TKI CONSORTIUM AGREEMENT

Title Project: PFASE-OUT: "Monitoring, removal and breakdown of PFAS in (waste) water."

THE UNDERSIGNED:

1 **Attero B.V.**, having its office at Vamweg 7, 9418 TM Wijster, the Netherlands;

2 **Aquatech Environmental Services**, having its office at One Four Coins Drive,Canonsburg, PA 15317,USA;

3 **Bio Detection Systems B.V.**, having its office at Science Park 406, 1098 XH Amsterdam, the Netherlands;

4 **Bluecon International B.V.**, having its office at IJsselsteyn 7, 6956 AZ Spankeren, the Netherlands;

5 **Boskalis Environmental B.V.**, having its office at Rosmolenweg 20, 3356 LK Papendrecht, the Netherlands

6 **Chemours Netherlands B.V.**, having its office at Baanhoekweg 22, 3313 LA Dordrecht, the Netherlands;

7 **DiaCCon GmbH**, having its office at Dr.-Mack Strasse 81, 90762 Fürth, Germany;

8 **echemtech**, having its office at Duinhuislaan 11, 2212 SB Noordwijkerhout, the Netherlands;

9 **Forever Analytical Solutions B.V.**, having its office at High Tech Campus 12, 5656 AE Eindhoven, the Netherlands;

10 **Het Waterlaboratorium**, having its office at J.W. Lucasweg 2, 2031 BE Haarlem, the Netherlands;

11 **N.V. PWN Waterleidingbedrijf Noord-Holland**, having its office at Rijksweg 501, 1991 AS Velserbroek, the Netherlands;

12 **Provincie Zuid-Holland**, having its office at Zuid-Hollandplein 1, 2596 AW 's-Gravenhage, the Netherlands;

13 **Smurfit Westrock Roermond Paper B.V.**, having its office at Mijnheerkensweg 18, 6041 TA Roermond, the Netherlands;

14 **Vereniging Innovatieve Geneesmiddelen**, having its office at Prinses Beatrixlaan 548-550 2595 BM Den Haag, the Netherlands;

15 **Vereniging van de Nederlandse Chemische Industrie**, having its office at Loire 150, 2491 AK Den Haag, the Netherlands;

The above partners individually referred to as "**Partner**" and together referred to as "**Partners**";

AND

16 **Stichting Wageningen Research, research institute Wageningen Food & Biobased Research**, having its office at Bornse Weilanden 9, 6708 WG, Wageningen, the Netherlands

("WFBR"); and **research institute Wageningen Food Safety Research**, having its office at Akkermaalsbos 2, 6708 WB, Wageningen, the Netherlands ("WFSR"), hereinafter referred to as "**WR**";

The above institute is referred to as "**Knowledge Institute**";

The Partners and Knowledge Institute hereinafter jointly referred to as "**Parties**" and individually referred to as "**Party**".

WHEREAS:

a) The Dutch government has deployed an innovation policy, which aims to strengthen the international competitiveness of nine leading industrial sectors (the Topsectors) through innovation;

b) This policy is implemented through the installation of a TKI per Topsector. The TKI has a role in determining the research agenda of the relevant Topsector. Ultimately, the respective ministry is responsible for granting public funding through the TKI;

c) Parties have expressed their willingness to participate in the TKI project "Monitoring, removal and breakdown of PFAS in (waste) water.", as described in the Project Plan, attached as Annex 1 and to this end have been granted funding by the respective ministry under the applicable conditions of the TKI. The EU Framework (available at https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52022XC1028(03)), Framework Decision National Grants of the Ministry of Economic Affairs ("Kaderbesluit nationale EZK en LNV-subsidies", available at https://wetten.overheid.nl/BWBR0024796) and/or subsidy regulations for applied research institutes "Subsidieregeling instituten voor toegepast onderzoek (TO2)" (available at https://wetten.overheid.nl/BWBR0040605) as amended or revised are applicable to this funding. Parties are aware that the Knowledge Institute will perform its tasks in conformity with the Netherlands Code of Conduct for Research Integrity 2018 (available at https://www.wur.nl/en/show/Netherlands-Code-of-Conduct-for-Research-Integrity-2.htm), or its successor;

d) the Parties now wish to lay down their arrangements with regard to the Project in this Consortium Agreement.

NOW, THEREFORE, IT IS HEREBY AGREED AS FOLLOWS:

Article 1: Definitions

"**Affiliate**" means an existing legal entity that controls a Party or that is under the control of a Party, or that is under the same control as the Party, control taking any of the following forms:

a) the direct, or indirect through (but not together with) other entities, holding of more than 50% of the voting rights of the shareholders or associates of that entity; or

b) the power to determine the policy of the legal entity concerned in a decisive way.

Parties will specify their Affiliates in a separate list included in Annex 6.

An Affiliate will be considered as being part of the respective Party throughout this Consortium Agreement.

"**Annex**" means any appendix attached to this Consortium Agreement.

"**Background**" means information, know-how, data or material, whatever its form or nature, which is either held by a Party prior to its accession to this Consortium Agreement or that has been developed or obtained by a Party thereafter independently from the Project, as well as any IP Rights pertaining to such information, know-how, data or material.

"**Confidential Information**" means any business information (including legal, financial, commercial, trade secrets and technical information), personal data and Background which the Receiving Party has received from the Disclosing Party in connection with the Consortium Agreement and (1) which is designated by the Disclosing Party as confidential or (2) which the Receiving Party reasonably can know or should know is confidential due to its nature.

"**Consortium Agreement**" means this agreement including all Annexes and addenda thereto.

"**Coordinator**" means the Party that is authorised by the other Parties to coordinate and manage the Project, having the tasks assigned to it under Article 4.

"**Disclosing Party**" means the Party disclosing Confidential Information to the Receiving Party.

"**Effective Date**" means the day that this Consortium Agreement enters into force, which is 1 June 2025.

"**EU Framework**" means the "*Framework for State Aid for Research and Development and Innovation*", as published in the Official Journal of the European Union, 2022/C 414/01.

"**Expiry Date**" means the last day that this Consortium Agreement is in force, and is the end date of the Project, which is 31 May 2028.

"**Field of Use**" means the application area per Party as specified hereafter:

a) Attero B.V. - Attero is cleaning PFAS contaminated Soil at its location in Wijster. During the treatment of this soil new technologies can be tested for more efficient treatment. Senior representative (Mr. Gert Brunink) to be appointed project lead.

b) Aquatech Environmental Services - PFAS Separation, Concentration and Destruction from waste streams, leachate, drinking water, ground water remediation, AFFF replacement, washwater from decontamination of PFAS material holding, PFAS manufacturing, industrial applications utilizing PFAS bearing compounds such as semiconductor, paper, coatings, etc.

c) Bio Detection Systems B.V. - Potential application in the field of safety evaluation of chemicals and environmental monitoring.

d) Bluecon International B.V. - Purification of municipal wastewater in countries where Bluecon is selling Bluecon units.

e) Boskalis Environmental B.V. - - Boskalis Environmental is cleaning PFAS contaminated soil in Amersfoort, conducting on a regular basis PFAS soil treatment test on our laboratorium. We are also interested in treatment in PFAS waterstreams from our processes, groundwater, etc.

f) Chemours Netherlands B.V. - PFAS abatement for waste water.

g) DiaCCon GmbH - Use of diamond electrodes in low concentrated waste water streams.

h) echemtech - Electrode materials, electrochemical (oxidation) reactors and integrated systems/installations for water treatment applications.

i) Forever Analytical Solutions B.V. - PFAS measurement / screening.

j) Het Waterlaboratorium - Research related to the development and implementation of analytical methods for monitoring and risk assessment of water quality. Research on water samples for drinking water companies, water boards and other partners and for own projects.

k) N.V. PWN Waterleidingbedrijf Noord-Holland – None.

l) Provincie Zuid-Holland – None.

m) Smurfit Westrock Roermond paper B.V. – None.

n) Vereniging Innovatieve Geneesmiddelen – Farmacy.

o) Vereniging van de Nederlandse Chemische Industrie – None.

p) WR – education & research.

"**Force Majeure**" means situations which impede performance of the Consortium Agreement by a Party beyond its control and for which this Party is not liable pursuant to the law, legal acts or generally accepted standards, including, but not limited to, situations such as pandemics and the loss of animals or plants used in performing the Project due to causes beyond the reasonable control of the Party affected.

"**Foreground**" means the results that are generated within the Project, including information, (raw) data, know-how and materials, regardless of whether or not such results are protected by IP Rights.

"**IDF**" means an invention disclosure form, to describe Foreground which may be protectable by IP Right(s), and of which a model is provided in Annex 4.

"**Intellectual Contribution**" means actively conceiving the idea, in an important way contributing to the development of the invention and providing solutions to problems in and during the Project. Mere efforts, ordinary assistance and the sharing of ideas, hypotheses and information, passively following instructions, performing routine tasks and executing result testing in and during the Project do not constitute to an intellectual contribution.

"**IP Flow Scheme**" means the process to determine ownership of Foreground and IP Right(s), and licensing opportunities, as specified in Annex 5.

"**IP Right(s)**" means plant breeder's rights, trademark rights, patent rights, designs and models rights, integrated circuit topography rights (computer chips rights), either applied for, granted or registered, or claims to any of the foregoing.

"**Market Conditions**" means conditions determined in accordance with generally accepted methods for IP Rights valuations (market based, income based, cost based as specified in the "Spelregels voor privaat-publieke samenwerking bij programmering en uitvoering van fundamenteel en toegepast onderzoek", available at https://www.topsectoren.nl/publicaties/publicaties/publicaties-2022/feb/240222/spelregels-pp-samenwerking) taking into account the Parties own contribution (in cash and/or in kind contributions) and percentage co-ownership, all in accordance with the EU Framework.

"**Member**" means a representative on behalf of a Party in the Project Committee.

"**Ministry**" means the Dutch ministry responsible for the funding and auditing of the Project, or - as the case may be - the respective governmental organisation acting on behalf of a Dutch ministry.

"**Project**" means all activities related to the project entitled: "Monitoring, removal and breakdown of PFAS in (waste) water." which shall be carried out on the basis of the Project Plan and which shall be governed pursuant to the provisions of this Consortium Agreement.

"**Project Budget**" means the allocation of all the resources, in cash and/or in kind, contributed by the Ministry, Partners and the TKI for the activities with regard to the Project (including managing costs of the Coordinator) as specified in the Project Plan.

"**Project Committee**" means the decision-making body as described in Article 4.

"**Project Plan**" means the research work plan and related Project Budget attached to this Consortium Agreement as Annex 1.

"**Receiving Party**" means the Party receiving Confidential Information from the Disclosing Party.

"**TKI**" means the Top Consortia for Knowledge and Innovation. This is a Public-Private Partnership which entails long-term partnership in concrete roadmaps for research & innovation across the entire chain, from fundamental research to demonstration projects.

Article 2: Purpose

The purpose of this Consortium Agreement is to specify the rights and obligations of the Parties with respect to the Project.

Article 3: Responsibilities of Parties

3.1 Each Party shall contribute to the efficient implementation of the Project Plan by carrying out the tasks allocated to it thereunder and shall cooperate, perform and fulfil on time, all of its obligations under this Consortium Agreement as may be reasonably required from it and in a manner of good faith.

3.2 Each Party undertakes to notify as soon as reasonably possible the other Parties of any significant information, fact, problem or delay likely to affect the Project.

3.3 Each Party shall provide as soon as possible all information reasonably required by the Project Committee or Coordinator to carry out its tasks. The Parties are not obliged to include Confidential Information in the Project, unless the Parties have agreed to disclose Background as described in Article 7.1 of this Agreement.

3.4 Each Party shall support the achievement of the goals of the Project.

3.5 A Party is only allowed to involve third parties other than its Affiliates in the execution of its tasks under the Project Plan upon prior approval thereof by the Project Committee. The Party that involves Affiliates or third parties for the execution of its Project tasks shall at all times remain responsible for the execution of its relevant part of the Project and for such third party’s or Affiliate’s compliance with the provisions of this Consortium Agreement. In addition the Party has to ensure that the involvement of third parties or Affiliates does not affect the rights and obligations of the other Parties under this Consortium Agreement.

3.6 In connection with the reporting requirements of the TKI and the Ministry, Parties acknowledge that the Knowledge Institute shall provide both the TKI and the Ministry with financial reports as well as scientific reports (which may include an abstract of the Project Plan) of the Project. Each Party shall provide promptly all information reasonably required by the Knowledge Institute to carry out this task.

Article 4: Governance structure

4.1 Parties appoint WFBR as Coordinator. The Coordinator shall, and the other Parties hereby authorise the Coordinator to carry out the tasks set forth under this Consortium Agreement which are specifically designated to the Coordinator. The Coordinator may delegate certain Coordinator tasks to another Party. The Coordinator shall remain responsible for Coordinator tasks carried out by such other Party.

4.2 In particular, the Coordinator shall be responsible for:

a) preparing the meetings, proposing decisions and preparing the agenda of the Project Committee, chairing the meetings and preparing the written minutes of the meetings, which shall be the formal record of all decisions taken. The Coordinator shall send the draft minutes to all Members within ten (10) calendar days of the meeting. The minutes shall be considered as accepted if, within eight (8) calendar days from sending, no Member has sent an objection in writing to the Coordinator, with respect to the accuracy of the draft of the minutes;

b) monitoring the implementation of decisions taken at meetings;

c) keeping the address list of Members and other contact persons updated and available;

d) collecting and reviewing information on the progress of the Project and submitting outline scientific reports and other deliverables (including financial statements and related certification), if required, to the TKI and other Parties;

e) promptly circulating the documents and information related to the Project to the Members;

f) providing, upon request, the Parties with official copies or originals of documents which are in the sole possession of the Coordinator when such copies or originals are necessary for the Parties to present claims; and

g) all communications with the TKI and the Ministry in relation to the Project on behalf of the Parties.

4.3 The Coordinator shall not be entitled to act or to make legally binding declarations on behalf of any other Party unless explicitly stated otherwise in this Consortium Agreement.

4.4 The Parties shall establish a Project Committee for the duration of the Project. The Project Committee shall consist of the Members. Each Party will appoint one Member to the Project Committee and each Member or its substitute will have one vote.

4.5 All Members:

a) shall use their best efforts to be present or represented at all meetings;

b) may appoint a substitute or a proxy to attend and vote at any meeting; and

c) shall participate in a cooperative manner in the meetings.

4.6 The Project Committee shall meet, either in person, by telephone or by other electronic means, on a regular basis, at least twice a year.

4.7 The Project Committee shall discuss the progress of the Project, such as planning, requests for withdrawal, content, Parties' compliance with obligations and the Foreground generated so far. The Project Committee shall take the following decisions and actions:

a) changes to the Project Plan (excluding the Project Budget);

b) amendments to Annex 2 "Background Included";

c) requests to involve third parties or updates of the list of Affiliates;

d) change of the Coordinator and inform the TKI of such substitution;

e) verifications according to the "IP Flow Scheme";

f) suspension of all or part of the Project;

g) decision on a Party's request for withdrawal from the Project and the approval of the settlement on the conditions of the withdrawal;

h) termination of the Project and the Consortium Agreement.

4.8 Decisions shall be taken unanimously by the Members of the Project Committee in meetings where all Members are present or represented. Decisions that need the approval of the TKI (such as substantial changes to the Project, Project Budget, involved Parties etc.) will only be effective after such approval is received. Any decision may also be taken without a meeting if all Members agree to the decision by email. Such decision will become effective as of the moment the Coordinator informs all Members of such decision.

4.9 In respect of the Ministry's special position in societal and political issues, Parties will grant the Ministry the right to delegate a governmental observer to attend meetings of the Project Committee (hereinafter referred to as: "**Delegate**"). The Delegate shall have no voting rights or other rights granted to the Members.

Article 5: Confidentiality

5.1 Each Party hereby undertakes during the Project and for a period of 5 (five) years as of the Expiry Date:

a) not to disclose another Party's Confidential Information to any third party without the prior written consent of the Disclosing Party;

b) not to use another Party's Confidential Information except during and solely for purposes of the Project; and

c) to ensure that internal distribution of another Party's Confidential Information shall take place on a strict need-to-know basis.

The aforementioned is not applicable to Confidential Information of which the Receiving Party can demonstrate that it:

d) was in the possession of the Receiving Party without confidentiality obligations prior to disclosure;

e) was already publicly available at the time of its receipt or has become publicly available thereafter through no fault or action of the Receiving Party;

f) has been obtained from a third party without an obligation to maintain confidentiality;

g) was developed by the Receiving Party outside the framework of this Consortium Agreement and completely independently of any such disclosure by the Disclosing Party under this Consortium Agreement;

Each Party agrees to destroy or return to the Disclosing Party all Confidential Information that has been disclosed to the Receiving Party including all copies thereof and to delete all information stored in a machine readable form to the extent practically possible, on request of the Disclosing Party, except as agreed otherwise in this Consortium Agreement. The Receiving Party may keep one copy of the Confidential Information to the extent it is required to keep, archive, or store such Confidential Information because of compliance with applicable laws and regulations or for the proof of ongoing obligations, provided that the Receiving Party complies with the confidentiality obligations herein contained with respect to such copy for as long as the copy is retained.

5.2 Each Party agrees that for as long as the Foreground has not been disseminated in accordance with Article 6 or the Review Period as specified in Article 6.2 has not yet lapsed, whichever is earlier, not to disclose the Foreground to any third party, without the prior written consent of all Parties, with the exception of those cases that are explicitly agreed upon between the Parties in this Consortium Agreement in deviation from this.

The aforementioned is not applicable to Foreground of which the respective Party making reference to such an exception can demonstrate that it:

a) was already publicly available at the time of its receipt or

b) has become publicly available through no fault or action of such Party;

c) is disseminated in accordance with Article 6 of this Consortium Agreement.

5.3 Parties will have the right to disclose another Party's Confidential Information and Foreground to involved and approved third parties solely for the execution of the Project, provided that they are bound by confidentiality and non-use obligations not less stringent than those contained in this Consortium Agreement.

5.4 The confidentiality obligations under this Consortium Agreement shall have no obstructing effect with regard to the communication with the TKI and the Ministry. The Party communicating with the TKI and the Ministry shall nevertheless use its reasonable efforts to ensure confidentiality.

5.5 If any Party is required to disclose another Party's Confidential Information or Foreground in order to comply with applicable laws or regulations or with a court or administrative order, nothing herein shall restrict the Party from disclosing such information, but only to the extent of such order, law or regulation and it shall, to the extent it is lawfully able to do so, prior to any such disclosure;

a) notify the Disclosing Party; and

b) comply with the Disclosing Party’s reasonable instructions to maximally protect the confidentiality of the information.

Article 6: Dissemination

6.1 The Parties shall endeavour to disseminate the Foreground. The Knowledge Institute shall be responsible for making Foreground available to the general public under the conditions specified in this Article. Nevertheless, in case (parts of) the Foreground includes source code and/or object code of software that will be developed as part of the Project, then such source code and/or object code shall not be disseminated to the general public.

6.2 The Parties shall have the right to disseminate either by publication or otherwise the Foreground in accordance with the terms of this Consortium Agreement. During the term of this Consortium Agreement, as well as for a period of 2 (two) years thereafter (hereinafter "Review Period"), the Party intending to disseminate Foreground shall provide the other Parties with the intended dissemination at least 30 (thirty) calendar days before the intended dissemination date. Any objection to the intended dissemination shall be made in writing to the Party intending to disseminate the Foreground within 30 (thirty) calendar days after receipt of the intended dissemination. If no objection is made within the time limit stated above, the dissemination is permitted.

An objection is justified if:

a) the proposed dissemination includes another Party's Confidential Information or Foreground; or

b) the objecting Party’s legitimate interests are harmed by the dissemination; or

c) the proposed dissemination includes Foreground for which IP Right(s) can be applied for and of which the objecting Party has expressed its interest to obtain a licence thereto or the transfer of ownership thereof in accordance with Article 9; or

d) the proposed dissemination takes place during the Project.

For the avoidance of doubt and in accordance with Article 5.1, Confidential Information of another Party may not be disseminated without permission of the Disclosing Party before the confidentiality period specified in Article 5.1 has lapsed.

6.3 The objection must include a precise request for necessary modifications. If an objection has been raised, the Parties involved shall discuss how to overcome the justified grounds for the objection on a timely basis (for example by amending the intended dissemination and/or by protecting information before dissemination), provided that the scientific integrity of the dissemination in conformity with the Netherlands Code of Conduct for Research Integrity 2018 is preserved. The objecting Party shall not unreasonably continue the opposition, where appropriate actions are performed following the discussion.

6.4 If the objection is based on Article 6.2(b), (c) or (d), the intended dissemination can be delayed for up to nine (9) months from the day the objection has been made to allow an application for IP Rights to be filed, to secure its interest or to modify the dissemination as described in Article 6.3. As from the expiration of this term, the Party wishing to disseminate will be entitled to proceed with the intended dissemination.

6.5 The provisions contained in this Article 6 shall not apply to communication with the TKI and the Ministry, including the submission of reports to the TKI and the Ministry as meant in Article 3.6. The content of these reports will be shared with the Parties before submission to the TKI and the Ministry. Parties acknowledge and agree that the TKI may publish summaries of the Project on their website.

6.6 The Parties undertake to cooperate to allow the timely submission, examination, dissemination and defence of any dissertation or thesis for a degree which includes the Foreground of the Knowledge Institute subject to the dissemination provisions agreed in this Article 6. In deviation of Article 6.4 if an objection is based on Article 6.2(b), (c) or (d), the dissemination can be delayed for a maximum of three (3) months from the day the objection has been made.

6.7 Nothing in this Consortium Agreement shall be construed as conferring rights to use in advertising, publicity or otherwise the name of the Parties, its employees or any of their logos or trademarks without their prior written approval.

6.8 The Party disseminating Foreground will acknowledge the funding of the TKI.

Article 7: Background

7.1 Background disclosed by a Party during - and for the purpose of - the Project, is and remains the (intellectual) property of and belongs exclusively to the Party who disclosed such Background. Each Party shall make available to another Party any Background necessary for the performance of the Project as described in Annex 2 with, if applicable, any limitations of use. The Parties nevertheless may contribute additional Background not listed in Annex 2, as far as necessary for the execution of the Project. This additional Background shall be added to Annex 2 when such addition has been agreed upon in a meeting of the Project Committee and included as separate bullet point, clearly indicated as "additional Background", in the minutes of such meeting without a signed amendment being needed.

Parties are not obligated to disclose (additional) Background for the Project, unless the Parties have agreed to disclose (additional) Background in accordance with this Article 7.1.

7.2 Each Party hereby grants to the other Party/Parties (including involved third parties permitted under Article 3.5) as far as needed by such Party/Parties in order to perform its/their tasks under the Project a non-exclusive, non-sublicensable, royalty free, non-transferable right to use its Background listed in Annex 2.

Nevertheless, Background disclosed by a Partner during and for the Project shall not be used to train or develop artificial intelligence or machine learning systems as part of the Project, without the written permission of the Partner disclosing the Background.

7.3 When technically or legally necessary for the use and exploitation of Foreground subject to rights granted under this Consortium Agreement, each Party shall upon request of another Party, grant to such Party a non-exclusive, worldwide, non-transferable licence to use its Background listed in Annex 2, subject to the limitations of use mentioned in Annex 2.

In case software forms part of or all of the Foreground, then such licence to use Background shall include access to Background software, hardware and IT systems, in case such access is required to be able to use the software which is part of the Foreground pursuant to Article 8.5, and solely for that purpose.

The conditions for such licence shall be fair, reasonable and non-discriminatory and the fee shall be calculated in an objective, reasonable manner, at arms' length. Such request to the owner of the Background has to be made within 12 (twelve) months after the Expiry Date. After this period the granting of such licence and the conditions thereof is at the discretion of the owner of the Background.

Article 8: Foreground

8.1 Foreground shall be the property of the Party that generated such Foreground. If particular Foreground has been generated by more than one Party and cannot be attributed to one Party or the other, these Parties shall jointly own such Foreground in accordance with Article 9.3.

8.2 Each Party hereby grants to the other Party/Parties (including its/their involved third parties as permitted under Article 3.5) as far as needed by such Parties in order to perform their tasks under the Project, a non-exclusive, royalty free, non-transferable right to use its Foreground.

8.3 The owner(s) of the Foreground is/are free to use its/their Foreground subject to the provisions in Articles 5.2, 6.2 and in accordance with arrangements between the Parties pursuant to Article 9.

8.4 The Knowledge Institute will at all times remain entitled to use all Foreground for internal research and educational purposes subject to the provisions of Articles 5 and 6.

8.5 Each Party shall have the right to use another Party's Foreground in as far as not protected by IP Rights for internal research and internal development purposes only. This neither includes the performance of services for third parties for a fee, nor manufacturing products for sale to third parties.

After dissemination of such Foreground in accordance with Article 6 or after the confidentiality period specified in Article 5.2 has lapsed, whichever is earlier, each Party will be free to use that Foreground which is not protected by IP Rights for all purposes.

In deviation of the above, if Foreground consists of software/(web based) applications or similar which are protected by copyright, the Parties will receive an option to obtain a licence to such Foreground which will be treated in the same manner as the option to obtain a licence to IP Rights as arranged in Article 9.8. The conditions for access to the source code and/or object code of the software will be agreed upon in a separate licence agreement. Such licence agreement shall contain the provision that any data generated by the licensee of the software by using that software shall be owned by that licensee. The licensee shall be allowed to use that data for all purposes, including commercial purposes.

8.6 Before dissemination of Foreground or before the confidentiality period specified in Article 5.2 has lapsed, whichever is earlier, and subject to Articles 3.5, 8.3-8.5 and 9.8, a Party is entitled to grant to a third party, being a service provider, a royalty-free (sub)licence to use the Foreground solely for the purpose of research activities for the benefit of such Party only. The Party will at all times remain responsible for such service provider and ensures that such third party will keep the Foreground strictly confidential in accordance with the provisions of this Consortium Agreement and that it shall only be used for said research activities.

Article 9: IP Rights, Licensing and Transfer of Ownership

<u>General</u>

9.1 If Foreground that can be protected with IP Rights is generated and/or identified by a Party, the owner(s) of such Foreground shall instruct its/their researchers to fill out an IDF in consultation with a patent specialist chosen by the Parties involved. Subsequently, the owner(s) of the Foreground shall send a draft IDF to all Parties. Within one month after receipt of the draft IDF, Parties can propose changes and additions to the draft IDF. After one month the owner(s) of the Foreground shall send a written notification, including the final and signed IDF, to all Parties.

The owner(s) has/have the exclusive right to apply for or register IP Rights on its/their Foreground in its/their own name and at its/their own expense.

9.2 If Background of other Parties is included in the draft IDF, these Parties can object to the inclusion of such Background in the IDF within one month after receipt of the draft IDF in accordance with Article 9.1. If an objection has been raised, the Parties involved shall discuss how to overcome the justified grounds for the objection on a timely basis (for example by amending the IDF). The objecting Party shall not unreasonably continue the opposition, where appropriate actions are performed following the discussion.

9.3 In case the Foreground for which protection by IP Rights will be sought is joint Foreground, the joint owners shall as soon as practicably possible execute a joint ownership- or transfer agreement in which they make arrangements regarding the transfer or licensing of the joint Foreground and/or financial compensation of the other owner(s) in accordance with the clauses of this Consortium Agreement and the IP Flow Scheme. This will be done within 6 (six) months (or in case of urgent filing requirements 2 (two) months) as of the date the final IDF is sent to all Parties and prior to the application or registration of IP Rights. The ownership share of the Parties shall be determined in good faith, taking into account each of the Parties' Intellectual Contribution to such joint Foreground.

In case of joint ownership of Foreground whereby Parties are unable to execute a joint ownership- or transfer agreement within the aforementioned period, then the Knowledge Institute shall apply for IP Rights on that Foreground in order to secure such IP Rights and costs of such filing will be equally split between the owners, unless agreed upon otherwise. All owners of this Foreground will be named as applicants of the IP Rights. After such filing the concerned Parties shall agree on the ownership and exploitation of such IP Rights in good faith.

9.4 The Parties shall be entitled to obtain from the owner(s) of the Foreground a licence on Foreground protected by IP Rights in their Field of Use under the conditions as specified hereunder.

The Parties shall inform the owner(s) of the Foreground in writing, within 45 (forty five) calendar days after receipt of the final IDF, whether they are interested in obtaining a licence to the IP Rights (to be) vested in the Foreground.

9.5 If one or more Parties are interested in obtaining a licence to such IP Rights, the owner(s) of the Foreground shall apply for or register IP Rights in its/their own name and at its/their own expense, and involve the interested Parties in the patent strategy, the countries in which to file, the phrasing of claims etc.

9.6 If none of the Parties are interested in obtaining a licence to such IP Rights, the owner(s) of the Foreground will still have the right to apply for or register IP Rights on the Foreground for its/their own (commercial) purposes and to transfer, or license such IP Rights to third parties.

9.7 If the IP Rights on Foreground are licensed to or owned by a Party other than the Knowledge Institute, the Knowledge Institute will at all times remain entitled to use such Foreground for non-commercial research and educational purposes subject to Articles 5 and 6.

Licence rights

9.8 A Party can exercise its option to obtain from the owner(s) of the Foreground a licence to use the protected Foreground for commercial purposes in their Field of Use, with the right to sub-license to its contracted manufacturers (hereinafter referred to as: "**Licence**") within the period as specified in Article 9.4. This Licence can be granted on a non-exclusive, semi-exclusive or exclusive basis, depending on the number of interested Parties. Only in the situation of an exclusive Licence, the licensee is allowed to provide sub-licenses to third parties.

If Licences are granted to more than one Party (when at least one of those Parties requested an exclusive Licence) for Fields of Use that overlap or concern consecutive steps (e.g. as parts of a value chain), then such Licences will become semi-exclusive, meaning that licensees are not entitled to limit the other licensee's Licence in the overlapping Field of Use or in the full exploitation of the consecutive step for which the Licence was obtained.

The conditions and fee for such Licence shall be determined in accordance with Market Conditions. The Licence fee shall be paid to the Party owning the IP Rights. In addition to the Licence fee, the concerned Parties may agree on a reasonable compensation for the annual maintenance costs of the IP Rights in the countries the licensee is interested in, which will be incurred each year by the owner(s) of the concerned IP Rights.

9.9 Should the concerned Parties be unable to agree on the Licence conditions, they shall, on a concerned Party's request, refer this dispute to an independent expert for a binding decision. The Parties concerned shall together appoint such independent expert and share the related costs equally. In case Parties cannot agree on the appointment of the independent expert Article 17.3 shall apply. Should the respective Parties be unable to agree on the terms of a licence agreement within a period of six (6) months after having exercised the option and not having involved the independent expert or if all concerned Parties elected to disregard the decision of the independent expert, the owner(s) shall have the right to license or transfer its/their protected Foreground to any third party. The owner(s) shall however – for a period of one year as of the termination of these negotiations - neither grant licences nor transfer the relevant Foreground and IP Rights to other Parties or third parties on more favourable terms (taking into account objective standards, such as Field of Use, geographical scope, exclusivity the contributions made by the Partners to the Project), than offered to the interested Part(y)(ies).

9.10 The litigation costs of the owning Party with respect to the IP Rights will not be included in the Licence fee or the compensation for the annual maintenance costs of the IP Right(s). In case litigation is contemplated, the Parties involved shall enter into further negotiations regarding the litigation and the division of the associated costs.

Transfer of Ownership

9.11 Article 9.1 to 9.10 are mutatis mutandis applicable to the transfer of ownership of IP Rights mentioned in Article 9.12.

9.12 A Party can request from the Knowledge Institute the ownership of the IP Rights vested in the Foreground of the Knowledge Institute within the 45 calendar days period and under the conditions as specified in Article 9.4. This request can only be made if the Field of Use of the requesting Party is similar to the application area of the IP Rights. The decision whether or not to grant the request is at the sole discretion of the Knowledge Institute.

9.13 The Knowledge Institute shall transfer the ownership of the IP Rights to the interested Partner(s), after payment by the acquiring Partner(s) of the application costs of said IP Rights and a purchase price determined in good faith and in accordance with Article 9.8.

9.14 If the ownership of the IP Rights on Foreground is transferred to another Party or third party, the Party transferring the IP Rights shall ensure that any such transfer shall be subject to all prior rights (including options and licences granted to Parties in accordance with Articles 8 and 9), commitments and undertakings entered into by that Party in respect of the existing rights to the Foreground and corresponding IP Rights prior to the date of any such transfer of the IP Rights.

9.15 Irrespectively of the above transfer of ownership unless specifically agreed upon otherwise, the original owner(s) shall exclusively retain the copyright to its reports, brochures, designs, blueprints, drawings, models, source code of software and/or in general any and each product in the field of literature, science and art, expressed in any manner or form whatsoever, which have been produced by the original owner(s) within the framework of the Consortium Agreement.

Article 10: Exchange of material

10.1 Any transfer of material during the Project may be subject to the conclusion of a Material Transfer Agreement. A template for a Material Transfer Agreement is attached to this Consortium Agreement as Annex 3.

10.2 The Parties acknowledge that to the use and/or transfer (to the other Parties or third parties) of "genetic resources", derivatives of genetic resources and/or "traditional knowledge", the terms, conditions and other provisions of the Nagoya Protocol, EU regulation 511/2014, the Convention on Biological Diversity and/or national legislation of the country of origin of such material may be applicable.

10.3 Parties undertake to comply with the applicable regulations specified in Article 10.2 and if these regulations apply, make (via the Project Committee) further arrangements regarding this subject matter, for example (but not limited to) on whether or not to jointly submit a so-called due diligence statement (EU-declare) as referred to in EU regulation 511/2014.

Both the providing Party (Parties) and the receiving Party (Parties) shall provide to each other all the information required for this purpose.

Article 11: Financing of the Project

11.1 The Project will be financed in accordance with the Project Budget as included in the Project Plan. All amounts are in Euro’s and excluding VAT or any other taxes.

11.2 All in kind and in-cash contributions to be made to the Project by each of the Parties are specified in Annex 1 to this Consortium Agreement. Each Party shall only be responsible for making its own contribution as specified in Annex 1.

The Knowledge Institute shall send invoices to each Partner separately for the amount due by such Partner according to the Project Budget for such year. In case no payment schedule is included payment will be due at the start of each Project year. In case of financing by governmental bodies a declaration can be send to such governmental bodies instead of an invoice. Invoices/declarations will be paid within 30 days of receipt thereof.

11.3 In accordance with its own usual accounting and management principles and practices - which may be verified by the TKI or the Ministry - each Party shall be solely responsible for justifying its costs and/or contributions with respect to the Project. Each Party shall provide the Coordinator with a director’s statement with regard to its justified costs regarding a calendar year, before 1st March of the subsequent calendar year. This director’s statement shall be signed by a Party’s legal representative. A template director’s statement can be obtained from the Coordinator.

Parties receiving an aggregate TKI-toeslag (as defined by the TKI) of EUR 125,000.- (one hundred twenty five thousand euro) or more shall be required to provide an audit certificate with regard to the expenditure thereof at its own costs.

If and when applicable, Parties (except Stichting Wageningen Research (“WR”)) receiving a yearly WR-capacity subsidy of EUR 125,000.- (one hundred twenty five thousand euro) or more, shall be required to provide a yearly audit certificate with regard to the expenditure thereof at its own costs ultimately before 1 May of the subsequent calendar year. The requirements for the audit certificate are specified in article 1.5 of the Regeling nationale EZK- en LNV-subsidies. In case the audit certificate is (partly) not accepted by TKI or the Ministry, the respective Party will be solely responsible for the restitution of such funds.

The Coordinator will not be involved in the (financial) reporting requirements in cases where Parties are obligated to report their expenditures directly to TKI or the Ministry.

Article 12: Limitation of liability and exclusion of warranties

12.1 Each Partner’s aggregate liability under or in connection with this Consortium Agreement towards the other Parties collectively shall be limited to an amount equal to once its total in-kind and in-cash contribution. The aggregate liability of the Knowledge Institute under or in connection with this Consortium Agreement towards a Partner individually, shall be limited to an amount equal to the total in-kind and in-cash contribution of that Partner.

12.2 Parties shall only be liable to any other Party for direct damages which does not include indirect damages such as but not limited to lost turnover, lost profits, loss of business or clients, loss of goodwill, penalties, fines, punitive damages, damage resulting from late delivery, reputational damage, or the loss of data and/or materials.

12.3 In the event that a Party does not or does not fully meet its committed in-kind contribution, such Party shall be obliged to pay the monetary equivalent of such in-kind contribution to the Party to which such contribution was due, without prejudice to the right of the latter to claim compensation for the actual loss suffered.

12.4 Each Party shall be solely liable for any loss, damage or injury to third parties resulting from the performance of the said Party’s obligations under this Consortium Agreement or from its use of Foreground or Background and indemnifies and holds harmless the other Parties against all claims of third parties to this end.

12.5 If and when a request (on behalf) of TKI or the Ministry for refunding of subsidy has been received the Party/Parties to which this can be attributed will be responsible for complying with such request. Such Party/Parties will indemnify and hold harmless the other Parties will indemnify and hold harmless the other Parties against any such claims for refunding of subsidy without the limitation of Article 12.1 being applicable.

12.6 The exclusions and limitations of liability stated in this Article 12 shall not apply to loss or damage arising out or in connection with:

a) the wilful failure or gross negligence of a party in performing its contractual obligations;

b) breach of Article 5 (Confidentiality); or

c) death or personal injury or loss or damage for which liability cannot be limited or excluded by law.

12.7 Parties give no warranties or guarantees, expressed or implied, for the Background and /or Foreground they provide to the other Parties, including merchantability or fitness for a particular purpose or that the use of the Background and/or Foreground will not infringe any intellectual property rights of a third party. The decision whether to use the Background and/or Foreground is the sole decision and responsibility of each Party and each Party shall assume sole responsibility for any claims or liabilities that may arise as a result of its use of the Background and/or Foreground. Each Party however shall inform the other Parties if it has knowledge that the use of Background or Foreground received or provided under the Project infringes the rights of a third party.

Article 13: Term

13.1 This Consortium Agreement shall become effective as of the Effective Date, provided that the Consortium Agreement has been signed by all Parties, and shall end on the Expiry Date. Parties shall execute the Project as specified in the Project Proposal within this period of time.

13.2 Six months before the Expiry Date, Parties shall consult with each other and the TKI whether an extension of the period provided in Article 13.1 is desirable.

Article 14: Termination

14.1 With regard to a Party:

a) that, except in case of Force Majeure, has not, not timely or not properly fulfilled an essential obligation under this Consortium Agreement and, after having been summoned thereto in writing, is still in default by not having properly fulfilled its concerning obligations within a reasonable term mentioned in the notice of default, without prejudice to the right of the other Parties to claim the losses they have suffered as a result of the default and/or termination of the Consortium Agreement;

b) that justifiably relies on Force Majeure which has lasted longer than ninety (90) days;

c) who is declared bankrupt, in respect of whom a suspension of payment is granted, an administration order is filed, a receiver is appointed in respect of its assets or a general assignment for the benefit of creditors is made; or

d) that goes into liquidation or that permanently discontinues its business;

the other Parties together, upon a majority vote, can terminate this Consortium Agreement towards said Party with immediate effect, without judicial intervention or any further summons being required, by giving notice by registered mail with return receipt. Said Party has no voting rights regarding the above decision to terminate its participation in this Project and this Consortium Agreement. The Consortium Agreement shall remain in full force and effect between the remaining Parties, unless the remaining Parties agree otherwise.

14.2 If the termination is based on Article 14.1(a), the Party whose participation in the Project has been terminated shall bear any reasonable and justifiable additional costs incurred by any of the other Parties in order to perform that defaulting Party’s tasks. At all times, the defaulting Party shall use its best reasonable efforts to limit damages and losses of the other Parties. The remaining Parties shall discuss how to deal with the excess amount or loss of funds, for example by amending the Project Plan.

14.3 When the participation of a Party has been terminated pursuant to Article 14.1, said Party shall not acquire any rights with regard to the Foreground, generated after the termination of its participation. Such Party's right to request a Licence to Foreground and the right to use

Foreground or Background shall cease immediately upon receipt of the formal notice of termination.

In addition, such Party shall continue the access rights it has granted to its Background and Foreground under this Consortium Agreement as if it had remained a Party for the whole duration of the Consortium Agreement.

14.4 Each Party is entitled to forthwith terminate the Consortium Agreement in the event of a final decision (not open to appeal) of the Ministry to discontinue funding the Project.

14.5 Articles 1 (*Definitions*), 5 (*Confidentiality*), 6 (*Dissemination*), 7 (*Background*), 8 (*Foreground*), 9 (*IP Rights*), 12 (*Limitation of liability and exclusion of warranties*), 14 (*Termination*), and 17 (*Applicable law and dispute*), as well as the Articles which, considering their nature, are intended to remain in force between the Parties after termination of this Consortium Agreement, or after termination of this Consortium Agreement towards a Party, shall survive termination of this Consortium Agreement.

Article 15: New party joining the Collaboration

If a new party wishes to join the Project, all Parties must agree to such acceding and the terms and conditions thereof in writing. An entity becomes a new Party to the Consortium Agreement upon signature of the accession document (Annex 7) by the new Party and the Coordinator. Such accession shall have effect from the date identified in the accession document. All Foreground developed before the accession of a new party shall be considered as Background of the owning Party with regard to such new party.

Article 16: Miscellaneous

16.1 If conflicts appear between the Annexes and the body text of this Consortium Agreement, the latter shall prevail.

16.2 Should any provision of this Consortium Agreement become invalid, illegal, unenforceable, or is not in accordance with the applicable regulations of the TKI and the EU Framework, it shall not affect the validity of the remaining provisions of this Consortium Agreement. In such a case, the Parties shall ensure that a valid and practicable provision shall be negotiated which fulfils the purpose of the original provision.

16.3 The Parties shall not be entitled to act or to make legally binding declarations on behalf of any other Party unless explicitly stated otherwise in this Consortium Agreement. Nothing in this Consortium Agreement shall be deemed to constitute a joint venture, agency, partnership, an offer by, or creating any obligation of any Party to enter into any form of agreement other than stated in this Consortium Agreement or interest grouping or any other kind of formal business grouping or entity between the Parties.

16.4 Unless explicitly mentioned otherwise in this Consortium Agreement, no rights or obligations of the Parties arising from this Consortium Agreement may be assigned or transferred, in whole or in part, without the other Parties' prior written approval, except that each Party shall have the right to assign all or part of its rights and obligations to an Affiliate. Nevertheless, the assigning Party shall inform the other Parties about such assignment as soon as reasonably possible.

In case of change of ownership of a Party prior consent from the other Parties is not required. The Party shall inform the other Parties about such transfer of ownership as soon as possible. Subsequently the Project Committee shall discuss the transfer of ownership. In case there is a conflict of interest, the other Parties together, upon a majority vote, can terminate this

Consortium Agreement towards said Party with immediate effect, without judicial intervention or any further summons being required, by giving notice by registered mail with return receipt. The Consortium Agreement shall remain in full force and effect between the remaining Parties, unless the remaining Parties agree otherwise.

16.5 Amendments and modifications to the text of this Consortium Agreement require a separate agreement between all Parties.

16.6 This Consortium Agreement may be executed in counterparts, each of which shall be deemed to be an original, and all of which shall together constitute one and the same agreement, and shall become effective as of the Effective Date, and when signed by each of the Parties and delivered to the other Parties by regular mail or by reliable electronic means.

16.7 If this Consortium Agreement is executed in electronic form then it will be provided to all Parties in PDF by e-mail or by electronic signing. All electronic copies of this Consortium Agreement shall together constitute one and the same agreement.

Each Party represents and warrants that it will comply with all applicable law, including in particular anti-corruption, antitrust, anti-money laundering or other criminal laws, rules or regulations with respect to the activities contemplated by this Consortium Agreement.

Article 17: Applicable law and disputes

17.1 This Consortium Agreement (and any questions regarding its existence, validity or termination) and the performance thereof is exclusively governed by Dutch law.

17.2 The Parties shall attempt to resolve any dispute arising out of or relating to this Consortium Agreement amicably.

17.3 Should Parties fail to resolve a dispute amicably, then such dispute shall exclusively be judged by the competent court in The Hague, the Netherlands.

Article 18: Annexes

18.1 The following Annexes form an integral part of this Consortium Agreement:

Annex 1: Project Plan and Project Budget;

Annex 2: Background Included;

Annex 3: Template Material Transfer Agreement;

Annex 4: Template Invention Disclosure Form (IDF);

Annex 5: IP Flow Scheme;

Annex 6: List of Affiliates;

Annex 7 - Accession document.

This Consortium Agreement has been signed by:

Attero B.V.

Name: Paul Ganzeboom
Position: CEO
Place/Country: Wijster, the Netherlands
Date: 23 mei 2025

Signature:
Ondertekend door:
Ganzeboom
51F29695699C487...

Aquatech Environmental Services

Name: Devesh Mittal
Position: Vice President
Place/Country: Canonsburg, USA
Date: 11 August 2025

Signature: Signed by:
Devesh Mittal
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Bio Detection Systems B.V.

Name: Em Prof.Dr. Bram Brouwer
Position: CEO
Place/Country: Amsterdam, the Netherlands
Date: 22 May 2025

Signature: DocuSigned by:
Bram Brouwer
65A220CBDEA04D3...

Bluecon International B.V.

Name: Engbert Lamberts
Position: Director
Place/Country: Spankeren, the Netherlands
Date: 22 mei 2025

Signature: Ondertekend door:
Engbert Lamberts
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Name: Bert Jan Pit
Position: Director
Place/Country: Spankeren, the Netherlands
Date: 23 mei 2025

Signature: Ondertekend door:
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Boskalis Environmental B.V.

Name: Menno Kaandorp
Position: Managing Director
Place/Country: Papendrecht, the Netherlands
Date: 24 mei 2025

Signature:
Ondertekend door:
Menno Kaandorp
B45084E9DE21469...

Chemours Netherlands B.V.

Name: An Lemaire
Position: Director
Place/Country: Dordrecht, the Netherlands
Date:

signed separately - see enclosed pdf

Signature:

DiaCCon GmbH

Name: Martin Rüffer
Position: Managing Director
Place/Country: Fürth, Germany
Date: 26. Mai 2025

Signature:
Signiert von:
Martin Rüffer
1928626B7EAE45B...

echemtech

Name: Sander ten Hoopen
Position: Director
Place/Country: Noordwijkerhout, the Netherlands
Date: 26 mei 2025

Signature: Ondertekend door:
Sander ten Hoopen
85BF7E9F1C48468...

Forever Analytical Solutions B.V.

Name: Cor Datema

Position: General Manager

Place/Country: Eindhoven, the Netherlands
Date: 22 May 2025

Signature: Signed by:
Cor Datema
C2D2BFF9A74A477...

Het Waterlaboratorium

Name: Dr. Heiko Teuber
Position: Director
Place/Country: Haarlem, the Netherlands
Date: 23 mei 2025

Signature: Ondertekend door:
345D8F89EA1F415...

N.V. PWN Waterleidingbedrijf Noord-Holland

Name: Martine Lodewijk
Position: Sectordirector Drinkwater Production
Place/Country: Velserbroek, the Netherlands
Date: 26 mei 2025

Signature:
Ondertekend door:
Martine Lodewijk
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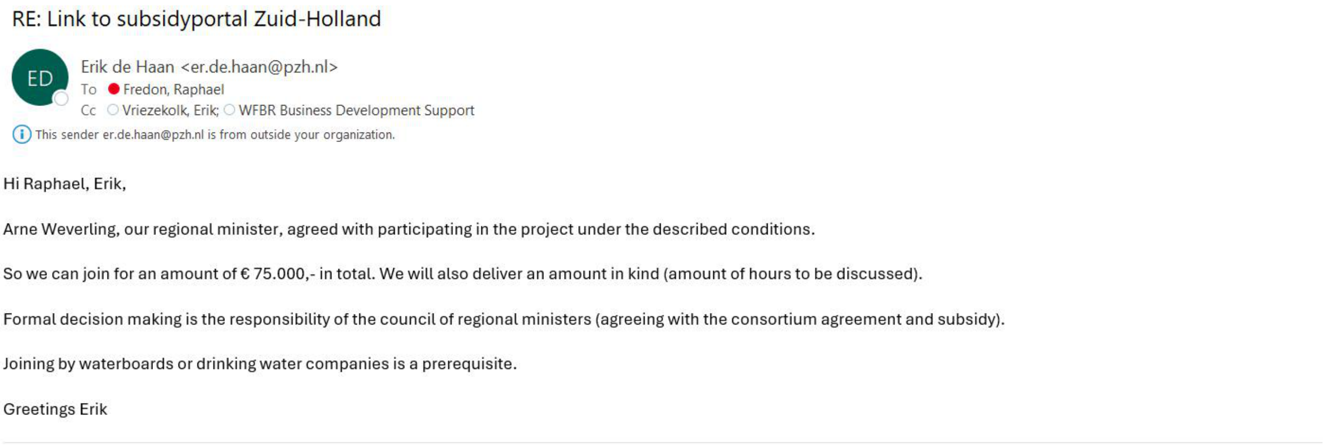
Provincie Zuid-Holland

Date: 3 February 2025
Signature:



RE: Link to subsidyportal Zuid-Holland

Erik de Haan <er.de.haan@pzh.nl>
To ● Fredon, Raphael
Cc ○ Vriezekolk, Erik; ○ WFBR Business Development Support
ⓘ This sender er.de.haan@pzh.nl is from outside your organization.

Hi Raphael, Erik,

Arne Weverling, our regional minister, agreed with participating in the project under the described conditions.

So we can join for an amount of € 75.000,- in total. We will also deliver an amount in kind (amount of hours to be discussed).

Formal decision making is the responsibility of the council of regional ministers (agreeing with the consortium agreement and subsidy).

Joining by waterboards or drinking water companies is a prerequisite.

Greetings Erik

Smurfit Westrock Roermond Paper B.V.

Name: Wouter H. Lap

Position: Managing Director

Place/Country: Roermond, the Netherlands
Date: 23 mei 2025

Signature:
Ondertekend door:
Wouter H. Lap
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Vereniging Innovatieve Geneesmiddelen

Name: C.B.J. Vos
Position: Managing Director
Place/Country: Den Haag, the Netherlands
Date: 22 mei 2025

Signature:
Ondertekend door:
C40032CC0E6D403...

Vereniging van de Nederlandse Chemische Industrie

Name: Manon Bloemer
Position: Director
Place/Country: Den Haag, the Netherlands
Date: 22 mei 2025

Signature:
Ondertekend door:
Manon Bloemer
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Name: Nienke Homan
Position: Chair
Place/Country: Den Haag, the Netherlands
Date: 23 May 2025

Signature:
Signed by:
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Stichting Wageningen Research
Research institute Wageningen Food & Biobased Research

Name: Dr.Ir. G.I.J. Feunekes
Position: Managing Director
Place/Country: Wageningen, the Netherlands
Date: 26 May 2025

Signature:
Signed by:
Dr Ir Gerda Feunekes
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Stichting Wageningen Research
Research institute Wageningen Food Safety Research

Name: Birgit P. Loos PhD
Position: Managing Director
Place/Country: Wageningen, the Netherlands
Date: 23 May 2025

Signature:
Signed by:
Birgit Loos
B8CA5C0780644D2...

Annex 1 - Project Plan and Project Budget

Template — March 2024

PPP proposal title: Monitoring, removal and breakdown of PFAS in (waste) water

Acronym: PFASE-OUT
(Persistent Fluor-Alkylated Substances Elimination - Operational Understanding and Treatment)

Please submit your proposal no later than 02 September 2024 via the submission link on [this page]

General information

Applicant/coordinator contact details (i.e. not the research institute)

Name: Engbert Lamberts
Organisation: Bluecon International
E-mail address: engbert.lamberts@bluecon.nl

Research institute contact details

Name: Raphael Fredon
Organisation: Wageningen University & Research (Food and Biobased Research)
E-mail address: raphael.fredon@wur.nl

The PPP proposal will contribute either to the following mission:

☐ 1. Nature
☐ 2. Sustainable agriculture and horticulture
☒ 3. Vital countryside in a climate-resilient Netherlands
☐ 4. Sustainable valued food, which is healthy, accessible and safe
☐ 5. The sustainable and safe use of the North Sea and large bodies of water
☐ 6. Safe deltas

Or the following key technology: ☐ ST1. Smart technologies for the blue-green domain
☐ ST2. Biotechnology and breeding
☐ ST3. Fermentation and bioconversion

Or the following:
☐ Crossover with TKI Life Sciences and Health (KIA Health & Care)
☐ Crossover with TKI Logistics (onderdeel van KIA Energy & Circularity)
☐ Crossover with TKI IT (KIA Digitalisation)

If a mission has been selected, which Innovation Programme and mission does the proposal relate to?

3C. Toekomstbestendig zoetwatersysteem (deelprogramma 3C2: schoon water, schone bodem)

TRL at the start of the project: TRL = 3

Brief summary of the PPP proposal

The quality of freshwater systems is a critical concern, under increasing pressure from environmental stress, climate change, and pollution, particularly from microcontaminants like PFAS. PFAS are persistent pollutants that pose significant health risks even at low concentrations and resist conventional treatment methods. Existing removal techniques often fail to fully degrade PFAS and may contribute to secondary pollution, leaving the environment vulnerable.

To address these challenges, the PFASE-OUT project will develop an integrated approach that combines advanced technologies for the detection, concentration, and complete degradation of PFAS. By creating a hybrid process that incorporates membrane filtration with tailored degradation methods such as electrochemical oxidation, plasma treatment, UV, and biodegradation, we aim to address various PFAS types and chain lengths. This comprehensive approach will overcome the limitations of individual technologies, enhance treatment performance, and ensure that PFAS are not returned to the environment. The project will engage key stakeholders—including waterboards, industrial companies, technology providers, local authorities, and research institutions—to monitor and treat PFAS across diverse water sources, including surface water, groundwater, and both industrial and municipal wastewater. Our ultimate goal is to produce PFAS-free water, enabling safe reuse of treated effluents and ensuring sustainable water management practices that protect public health and the environment.

PPP proposal (max. 10 pages)

1. OBJECTIVE AND EXPECTED RESULTS

1.1 Objective

A significant societal issue for the Netherlands and other countries is the need to improve and safeguard the quality of local and regional freshwater systems. Freshwater is, particularly in summer periods, already scarce and under increasing pressure due to environmental stress and climate change. An additional challenge is pollution from point and diffuse sources, especially due to the growing presence of microcontaminants such as pharmaceutical residues, microplastics and PFAS. These pollutants exacerbate the risks to ecosystems and the availability of clean water for drinking, agrifood, industry, and other uses. As a result, emissions into water and soil threaten to place unsustainable pressure on both the natural and human environment in the long term.

Over the last decade, per- and polyfluoroalkyl substances (PFAS) have become a major concern due to their widespread use, persistent nature, and potential adverse effects on the environment, safety, and human health. Often referred to as "forever chemicals," PFAS are synthetic compounds found in various consumer products, industrial processes, and firefighting foams. Their remarkable resistance to degradation has led to extensive contamination of water supplies, soil, and even the human body (see Figure 1).

PFAS contamination is pervasive in many water streams, including effluents from wastewater treatment plants (WWTPs, see STOWA), and industrial effluents. They contribute to the contamination of groundwater used for drinking water supplies (see RIVM, the Dutch National Institute for Public Health and the Environment), and surface water (RIVM) (see Figure 2). All these water sources are interconnected, spreading PFAS through rivers, lakes, and groundwater, which complicates its removal. Contamination of groundwater and surface water poses possible health risks associated as source for making water drinking, agrifood, etc., while polluted effluents contribute to further environmental degradation upon discharge. Additionally, PFAS contamination prevents these aqueous streams from being safely reused.

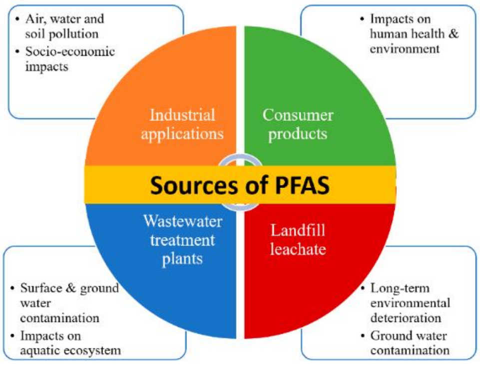
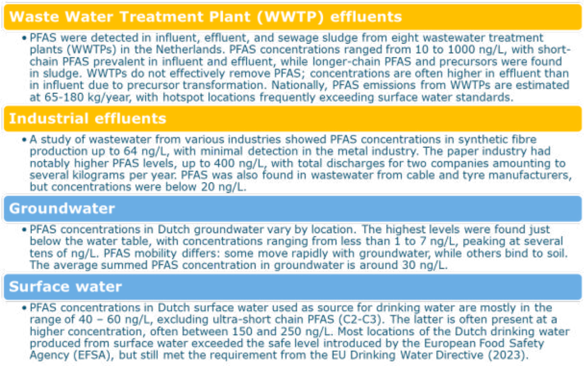


Figure 1. Sources of PFAS and their impact on the ecosystem via water, soil, and air pollution.



Waste Water Treatment Plant (WWTP) effluents

- PFAS were detected in influent, effluent, and sewage sludge from eight wastewater treatment plants (WWTPs) in the Netherlands. PFAS concentrations ranged from 10 to 1000 ng/L, with short-chain PFAS prevalent in influent and effluent, while longer-chain PFAS and precursors were found in sludge. WWTPs do not effectively remove PFAS; concentrations are often higher in effluent than in influent due to precursor transformation. Nationally, PFAS emissions from WWTPs are estimated at 65-180 kg/year, with hotspot locations frequently exceeding surface water standards.

Industrial effluents

- A study of wastewater from various industries showed PFAS concentrations in synthetic fibre production up to 64 ng/L, with minimal detection in the metal industry. The paper industry had notably higher PFAS levels, up to 400 ng/L, with total discharges for two companies amounting to several kilograms per year. PFAS was also found in wastewater from cable and tyre manufacturers, but concentrations were below 20 ng/L.

Groundwater

- PFAS concentrations in Dutch groundwater vary by location. The highest levels were found just below the water table, with concentrations ranging from less than 1 to 7 ng/L, peaking at several tens of ng/L. PFAS mobility differs: some move rapidly with groundwater, while others bind to soil. The average summed PFAS concentration in groundwater is around 30 ng/L.

Surface water

- PFAS concentrations in Dutch surface water used as source for drinking water are mostly in the range of 40 – 60 ng/L, excluding ultra-short chain PFAS (C2-C3). The latter is often present at a higher concentration, often between 150 and 250 ng/L. Most locations of the Dutch drinking water produced from surface water exceeded the safe level introduced by the European Food Safety Agency (EFSA), but still met the requirement from the EU Drinking Water Directive (2023).

Figure 2. Typical Dutch water effluents (orange) contributing to PFAS contamination of groundwater and surface water (blue).

Exposure to PFAS not only occurs directly through contaminated drinking water but also indirectly via the agri-food chain, as these chemicals accumulate in e.g. fish and chicken, and agricultural products irrigated with contaminated water. The persistence of PFAS allows them to accumulate over time, posing long-term risks to ecosystems and human health. Exposure to PFAS has been linked to numerous health issues, including cancer, thyroid disease, reproductive toxicities, reduced immune system functioning, and developmental problems in children. Despite growing awareness and regulatory efforts, e.g. for a ban on PFAS, effective solutions for addressing PFAS contamination remain limited and complex (see Annex 3). This challenge is exacerbated by the lack of natural degradation processes to break down PFAS, rendering traditional water treatment methods insufficient.

The most commonly found PFAS in groundwater and surface waters include PFOS (Perfluorooctane Sulfonic Acid), PFOA (Perfluorooctanoic Acid), PFNA (Perfluorononanoic Acid), and PFHxS (Perfluorohexane Sulfonic Acid). These long-chain PFAS ($C > 6$) are widely used in firefighting foams and coatings applications. Other, shorter chain PFAS have also been found frequently. Trifluoroacetic Acid (TFA), the smallest PFAS molecule ($C = 2$), is often detected as a breakdown product of other PFAS types and possible HCF refrigerants.

Objective of the PHASE-OUT project is the **adaptation, development, and deployment of innovative technology hybrids** for **detection, concentration, and maximal degradation of PFAS** (long-chain, short-chain) from four **practical water sources (use cases)**, including surface water, groundwater, industrial and municipal wastewater. Together with **key stakeholders** from the value chain— waterboards, industries, technology providers, local authorities and research institutions—we strive to create a **decentralized approach** to monitor and treat PFAS at water discharge and uptake sources (see Figure 3).

Hybrid Approach (Integrated System by Cascading of Technologies):

- **Concentration Step**: Implement nanofiltration / reverse osmosis for dewatering and concentration of PFAS.
- **Destruction Step**: Test and validate various destruction technologies (evaluation/testing of existing technologies UV, ozone, plasma treatment); development/testing of innovative technologies for electrochemical oxidation and biodegradation) to assess their effectiveness in degrading PFAS.
- **Detection Step**: Development and testing of an innovative PFAS screening method for effect-based detection.

Focus Areas:

- **Lab-Prototype Testing:** Validate integrated systems under real-world conditions.
- **Adaptation to Diverse Water Matrices:** Optimize selected water treatment technologies (including possible pretreatment) for four use cases, representing different water matrices and PFAS species (short-chain, long-chain)
- **Real-Time Monitoring and Adaptation**: Incorporate advanced sensing and monitoring technologies for real-time screening and effect-based detection of PFAS to determine, optimise and improve the treatment efficiency.
- **Economic and Operational Feasibility**: Assess the cost-effectiveness and practicality of single technologies and hybrids relative to traditional methods.

The **final goal** is to provide **robust, sustainable, and cost-effective solutions** for PFAS contamination that safeguard **water quality and public health** while promoting **sustainable water management** practices across all relevant water sources.

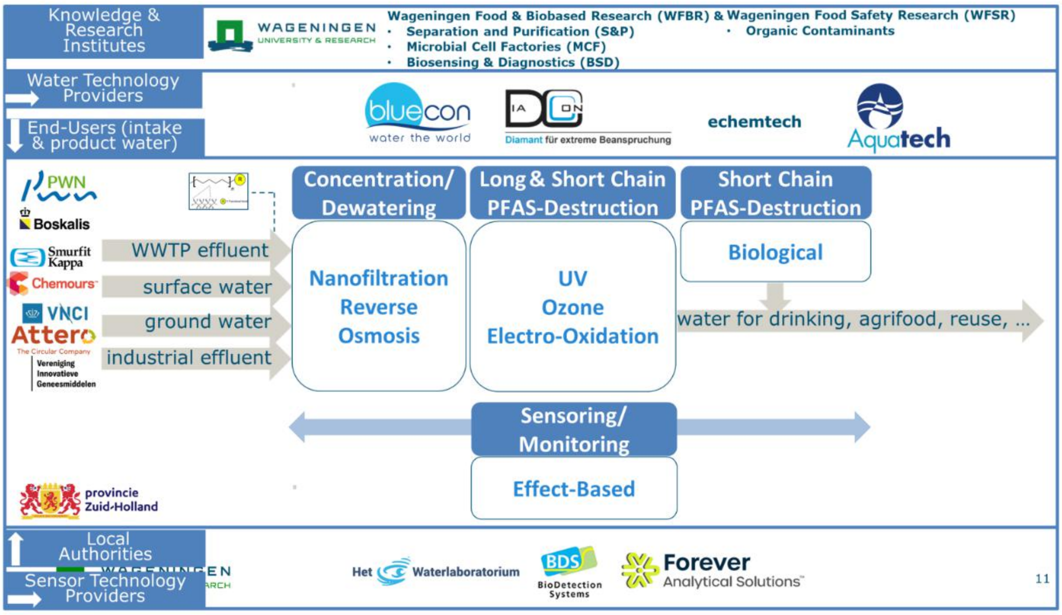


Figure 3. Value chain including stakeholders for decentralized monitoring and treating of PFAS at water discharge and uptake sources as proposed in the PFASE-OUT project.

1.2 Deliverables

The PFASE-OUT project will evaluate the technical potential of various **sensing, concentration, and degradation technologies** for PFAS removal from real streams. Initially, each technology will be tested at lab-scale and promising ones will be integrated in a prototype (***knowledge institutes***: **WUR-WFBR**, **WUR-WFSR**). The project will also evaluate the **techno-economic feasibility** and **social-ecological impact** of the integrated process with the involvement of all partners.

Proven feasibility of their technology is crucial for ***suppliers of water technology***, such as **Bluecon Internation** (water treatment), **AquaTech** (electrochemical oxidation), **echemtech** and **Diaccon** (electrodes for degradation reactions) as well as for ***suppliers of monitoring technology*** like **BioDetection Systems** (**BDS**) (in vitro test methods) and **Forever Analytical** (PFAS testing solutions) for **effect-based monitoring**. **Het Waterlaboratium** (independent water quality research company) is participating as an ***analytical end-user*** of the developed monitoring technologies. The **PFAS-free water product** is essential for end users like ***drinking water companies*** producing drinking water from groundwater and surface water (**N.V. PWN**) to meet the EU's 2026 Drinking Water Directive (PFAS levels ≤ 0.5 µg/L for total PFAS and ≤ 0.1 µg/L for each of 20 specific individual PFAS). ***Water boards*** (representatives), and ***industrial users*** like **Smurfit Kappa** and **Chemours** are also involved as current wastewater treatment plants struggle to fully remove PFAS. **Vereniging van de Nederlandse Chemische Industrie** (**VNCI)**, the industry association for the Dutch chemical sector, is present, as is **Vereniging Innovatieve Geneesmiddelen** (**VIG**), which represents companies that develop innovative medicines. Both act as ***umbrella organizations*** for companies dealing with PFAS-containing water. The project's results will help these users evaluate **new water sources or raw materials**. **Boskalis** is a ***dredging company*** involved in activities that encounter PFAS-contaminated groundwater. **Attero** is a ***waste management company*** also confronted with PFAS contamination in its operations. **Province Zuid-Holland** as a ***local authority***, supports the project, aiming to improve regional water quality and sustainability. Figure 3 shows an overview of the value chain including all stakeholders.

Besides the above specified deliverables for the partners, the project is also expected to provide a platform to:

- **Gain insights into water quality**: Understand the quality of the partners' water streams, including the types and concentrations of PFAS present and the amount discharged.
- **High-throughput detection method**: Develop an effect-based detection for initial screening, utilizing an array of PFAS binding proteins, some of these proteins linking to *in vivo* toxic effects. This enables detection of a broader range of PFAS compounds than current analytical technologies.
- **Study synergies between technologies**: Create a platform to explore the synergies between different technologies for PFAS concentration and degradation.
- **Technological advancement for on-site treatment**: Provide industrial companies with technological advancements for on-site treatment of wastewater or surface/groundwater. The developed integrated process focuses on maximum water recovery and preventing the discharge of contaminated water.
- **Validate new technology hybrids**: Roll out new technology combinations tested and validated with real water streams, opening new markets (in NL and abroad) and applications (PFAS from the four identified use cases, and as spinoff possibly for extracts of PFAS-unloaded adsorbents, or other microcontaminants/priority compounds such as pharmaceutical residues) for the technologies developed and commercialized by our partners.
- **Encourage policy change**: Persuade policymakers of promising alternative methods for the current approach to PFAS removal from water, i.e. adsorption and incineration, which is not environmentally friendly.

1.3 State of the art

PFAS contamination is a major environmental and public health concern, as evidenced by the substantial number of 140 review papers published since 2020. These overviews explore various aspects of PFAS, including their cycle, sources, types, physicochemical properties, toxicity, and impacts on safety, health, and the environment. They also cover treatment and remediation technologies (thermal, physical, (electro)chemical, biological), analytical techniques for detection, and advancements in sensing and monitoring. An extensive state of the art is reported in Annex 2 and summarised below.

(a) Current and Emerging Technologies

1) Current technologies
    - Active carbon adsorption: Adsorption using activated carbon and ion-exchange resins is the common benchmark for PFAS removal. However, the selectivity of adsorption is limited (due to TOC) and this method often requires subsequent incineration or disposal of spent adsorbent. This can result in secondary pollution and incomplete PFAS destruction. Regeneration of adsorbents often involves harsh chemicals and can produce toxic by-products.
    - Incineration: Although effective in destroying PFAS, incineration is energy-intensive and may release harmful (air) emissions if not properly managed. The high operational demands of incineration limit its practical application.
2) Emerging technologies for destruction of PFAS
    - Electrochemical oxidation: this technology is promising for degrading various PFAS types, but it typically requires high energy input and is validated only at the laboratory scale, with limited pilot-scale studies available.
    - Plasma treatment: plasma treatments can effectively break down PFAS molecules but involve complex, costly equipment and face scalability challenges.

- UV-photocatalysis: UV-photocatalytic methods, which use light to drive chemical reactions, have potential for PFAS degradation but currently suffer from limited efficiency and high operational costs.
- Biodegradation: biological methods for PFAS degradation are promising but are constrained by their effectiveness on specific short chain PFAS types and their slower processing rates.

Besides PFAS-destruction, some recent techniques focus on its concentration by nanofiltration and reverse osmosis, increasing selectivity and capacity of adsorption by using novel adsorbent materials such as functionalized pillarenes, mineralization of the PFAS-concentrated regenerate solution, or a combination of biological breakdown of organic substances and subsequent ozone treatment of the remaining organic pollutants (Aurea-technology). Recently, it was discovered that enzymes and/or bacteria from mushroom substrate are capable of biodegrading PFAS in water.

3) Sensing and monitoring
   - Advancements in analytical techniques: recent developments in analytical methods have enhanced the ability to detect PFAS in various matrices, such as air, water, soil, and biological samples. Improved detection methods are crucial for tracking very low PFAS concentrations, degradation products and assessing treatment effectiveness.
   - Real-time monitoring: recent advancements in biomonitoring have introduced Effect-Based Methods (EBMs) that use living cells or organisms to detect pollutants, offering insights beyond chemical analysis. While EBMs can detect a broad range of contaminants, challenges like maintaining organism health and labour-intensive processes limit their use in continuous monitoring.

(b) Synergistic Approaches and Future Directions

1) Synergistic treatment cascades
   - Integrated technologies: combining multiple treatment technologies into synergistic treatment cascades can enhance overall effectiveness by addressing the limitations of individual methods. These are categorised in Annex 2 (Table 7), using various criteria such as the degree of PFAS removal or degradation (long chain/short chain), by-product formation, quality of produced water, energy consumption, scale-up potential, and costs. Cost-effective treatment aiming complete PFAS degradation requires its concentration and subsequent destruction as can be realised by cascading at least two technologies.
   - In-situ remediation: synergistic methods that incorporate in-situ technologies can reduce the need for complex logistics and infrastructure, making treatment more practical for various real-world applications.
2) Optimizing process design
   - Customization based on PFAS composition: tailoring treatment technologies to the specific types of PFAS (short-chain vs. long-chain) and the water matrix conditions can improve efficiency and effectiveness. Different PFAS types require distinct treatment approaches, highlighting the need for adaptable technologies.

(c) Conclusions

The state of PFAS treatment and remediation reflects both progress and ongoing challenges. Traditional methods, such as adsorption and incineration, are limited by incomplete PFAS destruction and high operational demands. Emerging technologies offer potential alternatives but face scalability and operational challenges. The integration of multiple technologies into synergistic treatment cascades represents a promising approach, enhancing overall effectiveness and feasibility. Advances in sensing and continuous monitoring are needed, e.g. to avoid the challenges of maintaining live cells, for optimizing treatment processes and ensuring comprehensive PFAS management.

(d) Knowledge gaps

- **Integration of synergistic approaches (cascades, hybrids):** The practical implementation of synergistic treatment cascades that combine multiple technologies (e.g., concentration by nanofiltration/reverse osmosis, and destruction by electrochemical oxidation, plasma treatment, photocatalysis, biodegradation) remains underexplored. Research is needed to develop and validate these integrated systems for **complete PFAS degradation**. This includes achieving the degradation of all PFAS molecules into fundamental components.
- **Real-world testing in pilot plants**: Many emerging technologies have only been validated at the lab scale with synthetic waters. However, there is a gap in pilot and real-world testing of these technologies in combination, particularly for effluents from wastewater treatment plants (WWTPs) and industry, surface water and groundwater.
- **Adaptation to diverse water matrices**: Effective treatment requires adapting technologies to different water matrices and PFAS compositions (short-chain vs. long-chain). Research should focus on optimizing integrated systems for varying conditions to enhance their applicability.
- **Real-time monitoring and adaptation**: Advanced sensing and monitoring technologies, enabling effect-based screening of a large number of PFAS compounds, are crucial for optimizing treatment processes. There is a need for improved real-time monitoring and adaptive control to enhance the efficiency of integrated treatment systems.
- **Economic and operational feasibility**: The economic and operational implications of using integrated treatment systems need further investigation. Evaluating the cost-effectiveness and practicality of these approaches compared to traditional methods is crucial.

The PFASE-OUT project aims to address these gaps by evaluation/developing, testing and monitoring hybrid processes in a lab-scale prototype combining multiple innovative treatment technologies to achieve complete PFAS degradation for real water streams. These water streams include WWTP and industrial effluents, as well as surface and groundwater. Good and complementary connections can be made with current R&D initiatives for PFAS treatment (microbiological pretreatment to remove TOC, treatment of PFAS-concentrates, etc.).

2. PROJECT APPROPRIATE FOR THE KIA AND CONTRIBUTION TO PORTFOLIO

Our project aligns closely with the Key Innovation Agendas (KIAs), specifically targeting the priorities of **subprogram 3C2: Schoon Water, Schone Bodem**, which contributes to *Mission 3: Vitaal landelijk gebied in een klimaatbestendig Nederland*.

Figure 4 illustrates the KIA Theories of Change for Program 3C. The alignment of PFASE-OUT with the KIA priorities is highlighted, and the specific contributions to these key areas are detailed in the text box on the left side and below.

Gebruik zoetwatersysteem is in balans met aanvulling en waterbehoefte ecosystemen. Water wordt langer vastgehouden. Infiltratie zonder nadelige effecten op bodem en water. Waterverbruik is afgenomen. Vervuiling wordt voorkomen. Duurzame alternatieven voor waterwinning en waterhergebruik.

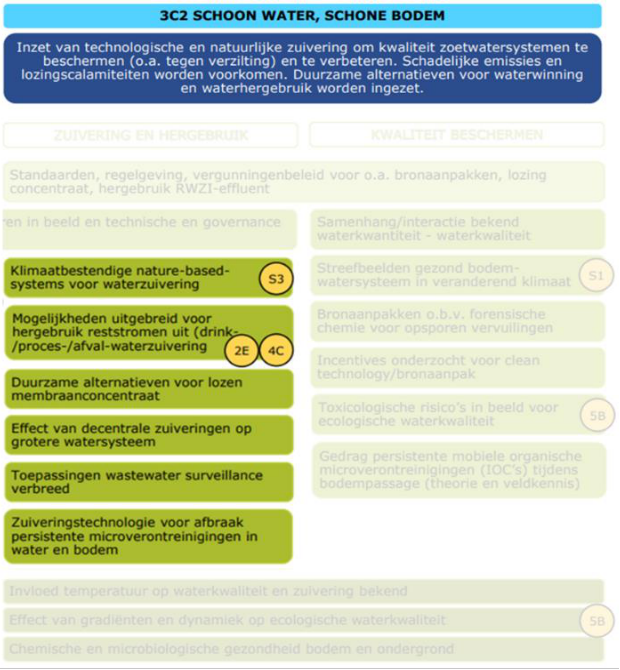


Figure 4. Overview of program 3C of the Kennis- en Innovatie-agenda Landbouw-Water-Voedsel 2024-2027 highlighting key contributions of this project (right hand side) and specifying connections (text box in left hand side).

- The project addresses various aspects included in *Vital countryside in a climate-resilient Netherlands*. Specifically, the impact and outcomes are relevant to innovation program *3C. Toekomstbestendig zoetwatersystemen*.
- The project focuses on developing advanced purification technologies for removing and degrading PFAS from water and rapid PFAS monitoring to ensure water quality. This approach directly contributes to improving water quality. It aligns with the KIA program, which aims to enhance freshwater and groundwater quality by addressing pollution from point sources such as wastewater treatment plants and industrial effluents (*Effect van decentrale zuiveringen op grotere watersysteem)*. Specifically, the project targets the degradation of PFAS, a persistent and harmful microcontaminant, to prevent its discharge into surface waters (*Zuiveringstechnologie voor afbraak persistente microverontreinigingen in water en bodem)*.
- The project promotes circular water use by treating effluents for reuse, which aligns with the KIA objectives for water conservation and reuse *(Mogelijkheden uitgebreid voor hergebruik reststromen uit drink-/proces-/afval-waterzuivering, 4C, 2E).*
- The project explores combinations of existing technologies that do not rely on incineration and investigate nature-based solutions such as biodegradation to create the most sustainable process possible (*Klimaatbestendige nature-based-systems voor waterzuivering, ST3*). This includes examining separation technologies like membrane filtration, where the concentrate is utilized for efficient PFAS degradation, thereby contributing to alternative solutions for disposing of membrane concentrate (*Duurzame alternatieven voor lozen membraanconcentraat, 2E).*
- The project supports public health by providing new solutions for ensuring that drinking water is free from PFAS, aligning with the KIA goal of guaranteeing the availability of safe drinking water and enhancing public health.

(i) Integration with running projects

The project builds on knowledge from running projects in water treatment and PFAS monitoring, further illustrating its good fit with the KIA agenda:

- Complementary Projects: Our project supports and complements initiatives such as *EffluentFit4Food* (LWV20021) and *Verwijdering van microverontreinigingen uit afvalwater* (WT2023UT01). These initiatives focus on removing micropollutants like pharmaceuticals and pesticides from water sources. Although they do not specifically target PFAS, their findings are highly relevant to our work. By integrating their results, we can ensure that our treatment process effectively addresses a broad range of contaminants. This comprehensive approach not only enhances the removal of PFAS but also improves the overall efficiency and effectiveness of water purification systems.

- Building on MEDALE: The *MEDALE* project (LWV21065) is developing technologies for micropollutant degradation, including small PFAS molecules. It has already achieved proof-of-principle for the degradation of small PFAS molecules, providing a solid foundation for further advancements in our project.

3. IMPACT

PFAS present a significant environmental and public health challenge due to their persistence in water bodies and their adverse health effects. Our project aims to address these challenges and deliver transformative impacts through the approaches as outlined below.

(i) Social-public

- **Enhanced water quality**: The project will develop advanced hybrid treatment technologies to effectively remove PFAS from effluents and other contaminated water sources such as surface and ground water. This will significantly reduce PFAS levels in these waters, improving overall water quality and reducing environmental contamination.
- **Healthier public**: Ensuring water for drinking, agrifood, etc., free from PFAS will improve public health outcomes by reducing the risk of exposure. Lowering PFAS discharge into surface waters will decrease the risk of exposure during recreational activities and the transfer to crops through irrigation, further protecting public health.
- **Air quality improvement**: The project will avoid energy intensive incineration methods and possible release of harmful emissions, opting instead for environmentally friendly PFAS destruction technologies. This will contribute to cleaner air and reduce the overall environmental impact of PFAS treatment.

(ii) Technical

- **Sustainable water management**: By enabling the reuse of treated effluents, the project will promote circular water use, decrease water stress, and support more sustainable water management practices.
- **Treatment of membrane concentrates**: While membrane filtration systems can effectively filter contaminants out of water streams, disposing of their concentrates remains problematic. This project will use membranes to concentrate PFAS contaminants, followed by treatment of the concentrate stream, ensuring comprehensive PFAS removal and reducing waste disposal challenges.

(iii) Economic

- **Economic evaluation**: Techno-economic analyses will validate the economic viability of these technologies, comparing the designed process with current PFAS treatment (adsorption followed by offsite incineration) and other water treatment technologies. Current emerging water treatment technologies for micropollutant removal have cost estimates ranging from € 0.15 to € 0.70 per cubic meter of purified water (Annex 2). The process designed in this project is expected to align with this cost range but to show an improved Value Proposition due to its environmental benefits (onsite destruction preventing transport towards (high temperature) incinerator, higher water recovery, and lower energy consumption).
- **New applications for technology providers**: Technology providers will benefit from testing and validating their (commercially available) technologies in a new application—PFAS removal. This project will offer valuable insights into the performance of their technologies within an integrated treatment chain, potentially leading to new market opportunities and enhanced technology development.

(iv) Knowledge development

- **Development of innovative treatment technologies**: Understanding and application of emerging PFAS removal technologies will contribute to the scientific and practical knowledge base. This includes integrating and optimizing various technologies for complete PFAS degradation and prototype-testing with real-world water samples.
- **Development of a new effect-based PFAS monitoring method**: An innovative effect-based PFAS monitoring method will be developed that enables the detection of a large number of (also unknown!) PFAS compounds based on their binding to (human) proteins, some of these proteins linking to the in vivo toxic effects of the compounds.

4. PROJECT APPROACH

The PFASE-OUT project is structured into ten work packages (WPs) across four phases, see Figure 5. Annex 3 gives an extensive description of the three-year work plan with all WPs, tasks (T), and deliverables (D). Milestone (M) is the selected process/technology cascade for integrated prototype testing and techno-economic social-environmental analysis (WP 6).

(a) Phase I: Technology and Use Case Evaluation

- **WP 1: Characterization of Water Streams of Use Cases**
  Analyse water streams of four use cases i.e. groundwater and surface water, and effluents from WWTP and industry.
  Result: Characteristics of water streams (composition, physical-chemical properties) of these streams (Months 1-4).
- **WP 2: Evaluation and Testing of Treatment Technologies**
  Evaluate and test existing treatment technologies for concentration (reverse osmosis) and destruction (UV/ozone, electrochemical oxidation), from technology providers with synthetic PFAS water.
  Result: Key performance indicators (effectivity and efficiency, operation conditions) of each technology, technology suggestions for full PFAS degradation, and potential of each technology for cascading (Months 3-15).
- **WP 3: Development and Testing of Electrochemical Oxidation**
  Develop and test an innovative electrochemical oxidation technology (as developed by WFBR for onsite production of green oxidants such as hydrogen peroxide, reactive oxygen and OH-radicals) with synthetic PFAS water.
  Result: Validated equipment components (electrodes, electrolytes), key performance indicators (effectivity and efficiency, operation conditions) of Electrochemical Oxidation, and potential for technology cascading (Months 3-15).
- **WP 4: Development and Testing of Microbiological Degradation**
  Develop and test microbial degradation processes for breakdown of short-chain PFAS compounds like trifluoroacetic TFA and evaluate for PFAS and PFAS derivatives originating from other treatment technologies.
  Result: Validated microbial strain, key performance indicators (effectivity and efficiency, operation conditions) for Microbial Degradation of short-chain PFAS/synthetic PFAS water and potential for cascading (Months 1-36).
- **WP 5: Development and Testing of PFAS-Screening Method**
  First, PFAS molecules are selected and conjugated to a fluorophore, and protocols for binding proteins are established. The binding of PFAS to these proteins is then confirmed. A database of signal profiles and an interpretation algorithm are developed. Sample pretreatment protocols for various water sources are established, followed by testing spiked PFAS mixtures and real samples. Finally, updates on the standardization of the screening method are provided.
- **Result:** PFAS detection method and sensor using reporter molecules and binding proteins (Months 1-36).

(b) Phase II: Lab-Prototype Testing

- **WP 6: Lab-Prototype Integration**
  Process designs based on input (e.g. stream composition of real water samples of four use

cases) and output parameters (target specifications) using simulation software and results from lab tests as determined in WP 1 – WP 4.
Result: Process design for feasibility of four use cases (Months 14-18).
Milestone: Selected process and technology cascade for integrated prototype testing and techno-economic, environmental & social analysis.

- **WP 7: Lab-Prototype Testing**
  Prepare and test the integrated prototype in a lab setting using real streams (use cases) and the PFAS sensor of WP5.
  Result: Proof of feasibility, validated integrated prototype, key performance indicators for full PFAS degradation (effectivity and efficiency, operation conditions) (Months 19-30).

(c) Phase III: Techno-Economic-Social-Ecological Evaluation

- **WP 8: Impact Assessment**
  Assess the cost, environmental impact, and stakeholder perceptions of the integrated process.
  Result: CAPEX, OPEX, investment, environmental impact, stakeholder perceptions, and benchmarks (Months 19-34).

(d) Phase IV: Organization

- **WP 9: Dissemination and Communication**
  Facilitate knowledge transfer and compile a final report.
  Result: Knowledge transfer documentation and final comprehensive report (Months 1-36).
- **WP 10: Project Management and Coordination**
  Manage project progress, meetings, and reporting.
  Result: Meeting schedules, minutes, disseminated results, project presentations and reports (Months 1-36).

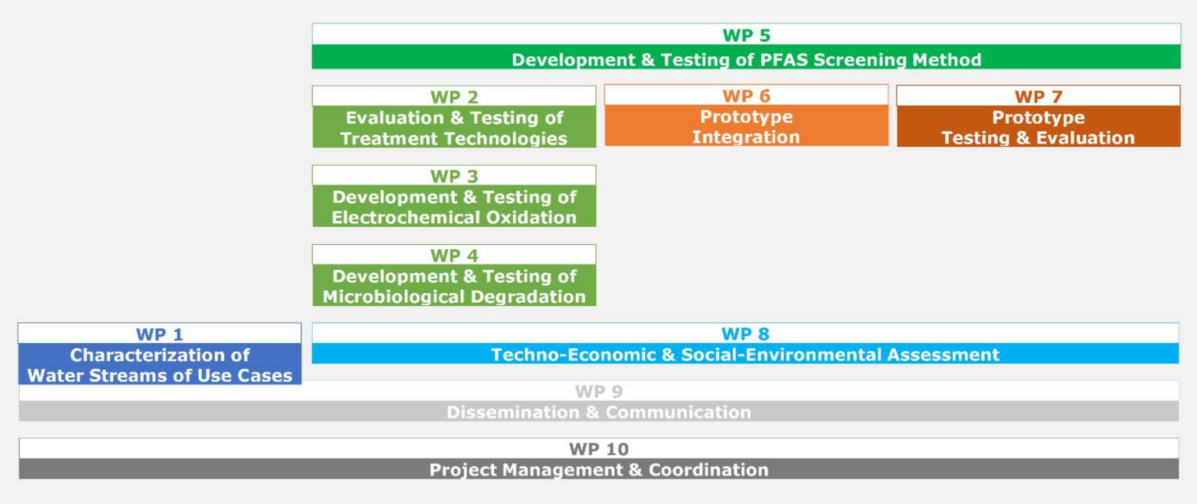


Figure 5. Schematic overview of the work package structure of the PFASE-OUT project (see Figure 14 for time schedule).

5. ORGANISATION

The project consortium comprises 17 partners covering the value chain. These include knowledge and research institutions, industrial companies, potable water providers, technology providers and local authorities responsible for wastewater treatment plants and water quality. A list of the partners, classified by type of organisation and their role in the project, is shown in Table 1. Additional information on the partners is given in Annex 3 and 4.

The project will be carried out in 3 years. WUR will be the project manager. Various expertise groups of WUR will conduct the research activities in the project. The progress of the project will be closely monitored by half-yearly meetings with all partners (kick-off, progress meetings, closing meeting).

Table 1. Partners and their role in the project.

Sector	Partners	Role in project
Knowledge and research institutes	• Wageningen Food & Biobased Research (WFBR)	WFBR is involved in planning and executing the monitoring, lab and prototype tests and is responsible for coordinating, dissemination and managing the project. Three expertise groups are involved covering water treatment, microbial conversion and biosensing & diagnostics.
	• Wageningen Food & Safety Research (WFSR)	WFSR handles the analysis and characterization of PFAS in water streams, analyses the effectiveness of PFAS degradation and removal, and maps the possible by-products that result from partial degradation, to apply primarily by deploying their analytical toolbox of CIC and LC-high resolution mass spectrometry.
Industry sector	• Smurfit Kappa • Chemours • Boskalis • Attero • VNCI • VIG	These industrial partners or umbrella organizations will provide • Data for characterization of contaminated water streams • Insights into current treatment procedures • Assistance in process operation during lab test Additionally, they will help guide the project's direction to ensure its relevance and applicability to the sector's needs.
Potable water providers	• N.V. PWN	
Technology providers	• Bluecon International • AquaTech • Diacccon • echemtech	These partners will contribute specialized knowledge, equipment, and technical support for their technologies, which will be tested and potentially implemented in the integrated prototype. Their involvement will play a pivotal role in the successful completion of the lab and protype tests.
Monitoring providers	• Biodetection Systems • Het Waterlaboratorium • Forever Analytical	These partners provide expertise in PFAS sensing and monitoring, supplying advanced technologies and technical support to enhance PFAS detection capabilities, including effect-based monitoring.
Governmental entities **(local authorities)**	• Province Zuid-Holland	Governmental entities bring knowledge about regulation, water quality, WWTPs and water management into the project. Additionally, they will help guide the project's direction to ensure its relevance and applicability to the sector's needs.

All project partners are integral to the value chain for purifying water streams contaminated with PFAS. Waterboards are focused on removing PFAS from their effluents to improve surface water quality and enable the reuse of treated effluents. Drinking water providers are concerned with ensuring the safety of drinking water from groundwater linked to surface waters, focusing on effective PFAS removal. Industrial partners aim to eliminate PFAS from their wastewater to guarantee safe discharge and facilitate the potential reuse of treated water. Provinces aim to enhance surface water quality across their regions. For all partners, ensuring water quality during PFAS removal is crucial. Consequently, they all have an interest in rapid PFAS detection technologies. The technology companies are introducing their innovative technologies into the project to achieve complete PFAS degradation in water streams.

6. KNOWLEDGE VALORISATION AND KNOWLEDGE SHARING

Disseminating and sharing knowledge is essential for applying the insights gained from this project to address PFAS discharge and promote water reuse in the industry. The knowledge acquired will be valuable to drinking water companies, water boards and industrial partners, including third parties and project collaborators.

6.1 Knowledge valorisation

The knowledge generated through this project holds substantial potential for a wide range of stakeholders, including drinking water providers, industrial partners, technology suppliers, local authorities, and knowledge & research institutes. To maximize the impact of our findings and ensure they are effectively utilized, we will implement the knowledge valorisation strategy as outlined in Table 2.

Table 2. Knowledge valorisation strategy.

Strategy	Activity	Responsible Parties	Timeline
Enhanced Collaboration	Organize workshops and technical meetings with industrial and potable water partners.	Project Manager, Technical Lead, Industry Partners	Month 16 and 30
Support for Industry and Consumer	Conduct tests of developed PFAS treatment technologies for selected cases.	Industry Partners, Technology Providers, Research Team	Start Month 16, ongoing through Month 36
Partnership Development	Host a technology demonstration day and matchmaking event for technology providers and end-users.	Project Manager, Business Development	Event after Month 16, follow-up after Month 30
Policy Influence	• Organize roundtable discussion with (local)authorities, and water boards. • Maintain regular contact with authorities to anticipate and adapt to policy changes	Project Manager, Communication Team	• Month 12 and 24 • Start Month 1, ongoing through Month 36
Knowledge Exchange	Engage in regular knowledge exchange sessions with running PFAS projects	Project Manager, Research Team	Start Month 1, ongoing through Month 36

6.2 Knowledge sharing

Effective communication is key to ensuring that the project's results are shared widely and utilized by all relevant stakeholders. Our comprehensive dissemination strategy includes the following components:

- **Regular Updates**: We will use standard communication tools, such as email, Microsoft Teams, and both live and virtual meetings, to provide continuous updates and maintain open lines of communication among all project partners. This will ensure that all participants stay informed about the project's progress and developments.

- **Dedicated Project Webpage**: A dedicated project webpage will be established to serve as a central hub for information. This webpage will provide stakeholders with updates, resources, and contact details. Additionally, the WFBR website and partner platforms like KennisOnline (KOL) will be utilized to reach a broader audience.
- **Final Report**: At the conclusion of the project, a comprehensive final report will be prepared, summarizing all findings and insights. This report will be accessible through KOL and other relevant platforms, ensuring that the results are readily available to all interested parties.
- **Conferences and Publications**: Key results and insights will be presented at national and international conferences and published in journals and magazines (e.g. Waterforum). This will allow us to share our achievements with the wider scientific community and industries and engage with experts in the field.
- **Public Outreach**: We will actively engage in public outreach activities through our networks, including press releases, social media campaigns, and public events. These efforts will help raise awareness about the project's objectives and achievements, fostering public support and understanding of the importance of PFAS treatment.

7. FUNDING AND BUDGET

An Excel template for drawing up a budget is available on the KIA website. Copy the summary of this budget below (Table 1). **Attention! See the call document for further details on different types of funding.**

Will any generated PPP balance be used?
(This only applies for parties that have generated a positive PPP balance with one of the TKIs in the past years. All parties have been informed about this.
☒ No
☐ Yes, please specify which TKI this relates to: …………

Have the partners in question already definitively confirmed the co-financing in the budget?
☐ Yes
☒ No, please specify which share of the co-financing has not yet been definitively confirmed:
100 k€ cash 100k€ in kind

Which funding model is the proposal based on?
☒ standard: 50% co-financing, of which up to 20% is public funding
☐ exception 1: 30% co-financing, agreements have been made with the Ministry of Agriculture, Nature and Food Quality or the Ministry or Infrastructure and Water Management (LNV or I&W) (fill in the name of contact details)
☐ exception 2: 50% co-finance, of which up to 40% is public funding
(See the PPP call document for a description of the three options. Please note: Exceptions 1 and 2 can only be granted if it is apparent from the proposal that all the requirements have been met).

Please note:

a. Regardless of the funding option, **at least 75%** of the total cost of the project must be **funded in cash**.
b. Contributions by **public partners** other than public research organisations must always be **in cash**.
c. A minimum **private contribution in cash of 5%** of the total project budget is applicable to all projects.

Table 3. Cost and funding summary (copy this table from the Excel file)

Costs	2025	2026	2027	2028	2029	Total
	Amounts in K€ (excl. VAT).					
Cost knowledge institutes	207,5	415,0	415,0	207,5	0,0	1.245,0
Cost other project partners	129,6	262,2	262,2	129,6	0,0	783,6
Overall Costs	**337,1**	**677,2**	**677,2**	**337,1**	**0,0**	**2.028,6**
Financing						
Co-financing	**2025**	**2026**	**2027**	**2028**	**2029**	**Total**
In-kind contribution private partners	129,6	262,2	262,2	129,6	0,0	783,6
In-kind contribution public partners	0,0	0,0	0,0	0,0	0,0	0,0
Cash contribution private partners (table cash)	35,0	70,0	70,0	35,0	0,0	210,0
Cash contribution public partners (table cash)	12,5	25,0	25,0	12,5	0,0	75,0
Total co-financing	177,1	357,2	357,2	177,1	0,0	1.068,6
Requested public contribution	**2025**	**2026**	**2027**	**2028**	**2029**	**Total**
WR capacity requested or TO2 contribution	0,0	0,0	0,0	0,0	0,0	0,0
PPP grant requested	160,0	320,0	320,0	160,0	0,0	960,0
Total public contribution requested	160,0	320,0	320,0	160,0	0,0	960,0
Total cash/public contribution in the project	207,5	415,0	415,0	207,5	0,0	1.245,0
Total financing	**337,1**	**677,2**	**677,2**	**337,1**	**0,0**	**2.028,6**

[1] This may only be included in the required minimum co-financing amount subject to certain conditions; see the 2024 PPP call for more.

Name of partner contributing the cash	Name of partner receiving the cash	Value of cash contribution in k € (excl. VAT).					
		2025	2026	2027	2028	2029	Total
Bluecon International	WR - WFBR	5,0	10,0	10,0	5,0		30,0
Bio Detection systems BV	WR - WFBR	0,0	0,0	0,0	0,0		0,0
Chemours	WR - WFBR	0,0	0,0	0,0	0,0		0,0
Het Waterlaboratorium	WR - WFBR	0,0	0,0	0,0	0,0		0,0
N.V PWN	WR - WFBR	7,5	15,0	15,0	7,5		45,0
Smurfit Kappa Europe BV	WR - WFBR	0,0	0,0	0,0	0,0		0,0
Vereniging van de Nederlandse Chemische Industrie	WR - WFBR	0,0	0,0	0,0	0,0		0,0
VIG	WR - WFBR	2,5	5,0	5,0	2,5		15,0
Diaccon	WR - WFBR	0,0	0,0	0,0	0,0		0,0
Echemtech	WR - WFBR	0,0	0,0	0,0	0,0		0,0
Boskalis Environmental	WR - WFBR	15,0	30,0	30,0	15,0		90,0
Attero	WR - WFBR	2,5	5,0	5,0	2,5		15,0
Forever Analytical	WR - WFBR	0,0	0,0	0,0	0,0		0,0
AquaTech	WR - WFBR	2,5	5,0	5,0	2,5		15,0
Province Zuid-Holland (publiek)	WR - WFBR	12,5	25,0	25,0	12,5		75,0
TOTAL cash contributions private partners		47,5	95,0	95,0	47,5	0,0	285,0

Private partners	Value of in-kind contribution in K€ (excl. VAT).					
	2025	2026	2027	2028	2029	Total
Bluecon International	10,0	20,0	20,0	10,0		60,0
Bio Detection systems BV	5,0	10,0	10,0	5,0		30,0
Chemours	10,0	20,0	20,0	10,0		60,0
Het Waterlaboratorium	10,0	20,0	20,0	10,0		60,0
N.V PWN	5,0	10,0	10,0	5,0		30,0
Smurfit Kappa Europe BV	22,5	45,0	45,0	22,5		135,0
Vereniging van de Nederlandse Chemische	0,6	1,2	1,2	0,6		3,6
VIG	7,5	15,0	15,0	7,5		45,0
Diaccon	5,0	15,0	15,0	5,0		40,0
Echemtech	4,0	6,0	6,0	4,0		20,0
Boskalis Environmental	15,0	30,0	30,0	15,0		90,0
Attero	7,5	15,0	15,0	7,5		45,0
Forever Analytical	7,5	15,0	15,0	7,5		45,0
AquaTech	20,0	40,0	40,0	20,0		120,0
Province Zuid-Holland (publiek)	NA	NA	NA	NA		0,0
Total excl. VAT private	129,6	262,2	262,2	129,6	0,0	783,6

Signature(s) for agreement:

Knowledge institution: Wageningen Food & Biobased Research

Name: Irma Steemers

Signature:

Date: 30-08-2024

Private lead:

Name and company/organisation: Paul Leenders VitalFLuid

Signature:

Date:30-08-2024

APPENDICES

Annex 1: Impact Plan

(a) Part A. Problem analysis

1a. Societal issue and causes

This project aims to mitigate the adverse effects of PFAS contamination on water quality, crucial for both drinking and irrigation in the Netherlands and abroad. The problem is exacerbated by the persistence of PFAS in surface and groundwater, further intensified by industrial contributions and inadequate removal strategies. PFAS-contaminated water poses significant challenges to human health, agricultural productivity, and ecosystem vitality.

The most relevant stakeholders/actors are:

- **Waterboards:** Manage WWTPs and need improved PFAS removal technologies.
- **Industrial sectors:** Release PFAS into water bodies and require new treatment technologies.
- **Drinking water companies:** Need advanced technologies to ensure safe drinking water.
- **Agricultural, food and other industries**: Concerned with ensuring that (food) products remain healthy and safe.
- **Technology providers:** Develop and supply PFAS removal and sensor technologies.
- **Universities & Research Institutes**: Conduct studies to understand PFAS behaviour and impacts, develop innovative removal and treatment technologies, and address knowledge gaps.
- **Government agencies:** Regulate and monitor water quality and policies.
- **The public:** Directly affected by PFAS contamination through drinking water and recreational activities.

A primary challenge for all stakeholders is the lack of effective, cost-efficient treatment and monitoring technologies for removing and measuring PFAS from affected water supplies.

1b. Main causes and knowledge gaps

The primary approach to address PFAS contamination (besides prohibiting or restricting the use of PFAS in industrial processes and consumer products) is **Water Treatment and Remediation**: i.e. to develop and implement advanced water treatment technologies to remove PFAS from contaminated water sources.

Current PFAS removal methods usually involve adsorption and incineration, but these approaches contribute to pollution and do not achieve complete PFAS destruction [1,2]. Emerging technologies like electrochemical oxidation, plasma, UV-photocatalysis, and biodegradation show promise for breaking down different PFAS types, but they have only been tested in laboratory settings with synthetic waters [3]. In addition, current PFAS detection technologies are time-consuming, expensive and only detects tens of compounds out of thousands PFAS molecules being around [4,5].

There is a **notable gap in the development of processes that integrate these technologies** to complement each other for **complete PFAS degradation** (i.e. complete degradation of all PFAS molecules into fundamental components), and there is a **lack of prototype/pilot-scale testing with real-world water samples**. In addition, understanding is needed about the **effectiveness in diverse conditions** (how new technologies perform across varied environmental conditions and PFAS concentrations), **long-term sustainability** (evaluation of long-term operational and maintenance needs of new technologies), and **impact on byproducts** (investigation into potential formation of harmful byproducts during PFAS degradation processes).

This project addresses these gaps by developing and testing a comprehensive process combining multiple hybrid technologies for effective PFAS removal and degradation in water streams, including WWTP and industrial effluents, surface water, and groundwater. While the focus is on these streams, the technology can be applied to other PFAS-contaminated sources. Additionally, the project will create an effect-based monitoring method to detect a broader range of PFAS, including those with unknown structures, surpassing current analytical capabilities.

(b) Part B. Impact pathway

2. Societal impact (= desired changes in the long term)

The project aims to drive long-term societal changes by implementing innovative hybrid technologies and monitoring for PFAS removal and management, leading to the following key impacts:

- **Water Quality Improvement**: By deploying advanced at the source treatment technologies, the project will reduce PFAS discharges into water bodies, enhancing the quality and safety of both drinking water and aquatic ecosystems.
- **Water Savings**: Treating industrial and municipal effluents for reuse will alleviate water stress by promoting circular water use, ensuring a sustainable supply of clean water for various industries and communities.
- **Public Health Improvement**: Providing PFAS-free drinking water will enhance public health by reducing exposure to these harmful chemicals, thereby decreasing the risk of associated health issues such as cancer and developmental problems.

This project may therefore also contribute to **Resource Efficiency and Circular Economy Adoption** (the recovery and reuse of treated water, reducing waste and conserving natural resources), **Increased Public Awareness** (demonstrating the successful application of PFAS treatment technologies in a lab-prototype will raise public awareness about the importance of water quality and encourage support for sustainable practices) and **Economics** (ensuring a reliable supply of clean water and reducing the burden of health-related costs due to PFAS exposure).

3.1 Effect (= required actions and activities in the medium term; also known as 'outcome')

Table 4 lists expected outcomes and the actions required to come to the societal changes addressed in the previous section.

Table 4. Stakeholder actions for achieving the targeted long-term societal impact

Public or private party	**Action, activity, and/or change in behaviour**	**Project-generated knowledge**
Waterboards	• Adopt technologies for PFAS removal and monitoring. • Reuse treated effluent in agriculture/ industry. • Collaborate with other entities for best practices.	• Integration of treatment technologies. • Rapid PFAS detection technology. • Evaluation of treatment processes. • Case studies on economic benefits. • Custom solutions for industry-specific needs. • Efficient integration into water management.
Industrial Companies	• Implement technologies for PFAS removal. • Reuse treated effluent. • Develop custom solutions with providers.	
Drinking Water Companies	• Adopt PFAS removal technologies. • Integrate monitoring systems. • Educate public on PFAS risks.	
Technology Providers	• Develop scalable solutions for treatment. • Collaborate on complete PFAS processes. • Innovate with research institutions.	• Performance data and technology synergies. • Upscaling considerations.
Governmental Agencies	• Encourage PFAS technologies via regulations/subsidies. • Set guidelines for PFAS technologies.	• Techno-economic & environmental evaluations.
Research Institutes	• Share use case studies with stakeholders. • Promote new PFAS technologies. • Promote analytical toolbox	• Lab and prototype-scale testing results. • Data on PFAS contamination in water streams and effectiveness of removal technologies.

		• Economic and sustainability assessments.

3.2 Project results (= knowledge or insights directly generated by the project: project results; i.e. 'output')

The project will deliver the following results ("output"):

- **Knowledge of PFAS in various water streams**: Detailed characterization of water bodies to identify PFAS types, concentrations, and variability over time.
- **Key Performance Indicators (KPIs) for various technologies**: Results from developing and testing water treatment and monitoring technologies for effective PFAS removal and destruction in synthetic samples.
- **Conceptual design of processes**: Development of integrated process designs for different PFAS-contaminated water streams, combining complementary technologies (hybrids).
- **Process testing:** Evaluation of processes using real-world contaminated water streams to ensure practicality and effectiveness beyond lab-scale tests.
- **Techno-economic analysis (TEA)**: Evaluation of the economic viability and cost-effectiveness of PFAS removal processes, including market feasibility.
- **Environmental Impact Assessment (EIA)**: Assessment of the environmental impacts associated with PFAS removal processes, focusing on the potential effects on resource usage, and pollution reduction.

3.3 Impact pathway assumptions

The following assumptions are made concerning the impact pathway:

- **Effective technologies**: Assumes technologies will successfully remove, degrade and monitor PFAS.
- **Design and validation:** Assumes designed processes will perform robustly in real conditions.
- **Economic viability:** Assumes findings will demonstrate the processes' economic feasibility and market acceptance.
- **Environmental benefits:** Assumes processes will show superior environmental performance.
- **Stakeholder engagement**: Assumes effective collaboration will support adopting advanced technologies.

Annex 2: State-of-the-art & deliverables

This chapter extensively outlines the current state-of-the-art on PFAS removal, degradation, and monitoring in water streams. It identifies gaps in achieving an efficient and environmentally acceptable process and describes how this project aims to address these gaps and deliver specific outcomes. The technologies to be employed in this project will be selected through a screening of emerging, promising technologies. Decisions will be based on key performance indicators obtained from lab-scale studies found in the literature, such as degradation efficiency, energy costs, and scalability. We will evaluate both degradation techniques and separation technologies for PFAS removal, with the goal of combining these methods to develop an efficient overall process.

(c) PFAS Types and structure

PFAS is a collective term for over 6,000 compounds that include combinations of fluorine atoms and alkyl groups. PFAS molecules and their exposure pathways pose significant and growing concerns for human health and the environment[6,7].

PFAS molecules consist of a hydrophobic fluorinated tail of varying lengths and a hydrophilic head that can contain different functional groups, such as carboxylate, phosphate, or sulfonate groups. The diverse physicochemical properties of PFAS molecules affect the efficiency of separation, degradation, and monitoring technologies. A schematic representation of various PFAS classes is shown in Figure 6.

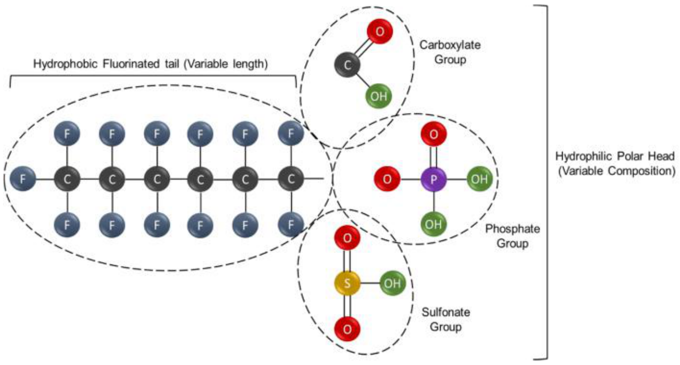
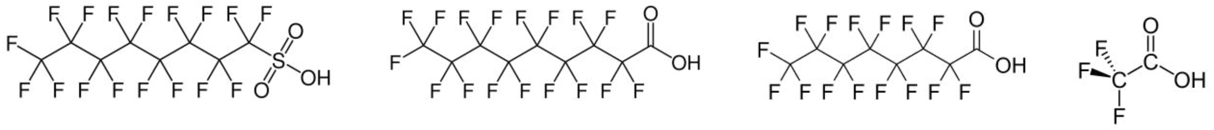


Figure 6. Overview of the general structure of non-polymeric, perfluorinated PFAS substances. Non-polymeric PFAS are compounds of variable composition and physicochemical properties that share two common features. These are represented by the hydrophobic tail, composed of a variable number of carbon atoms at different degrees of fluorination, and the hydrophilic head, which contains polar groups. The specific combination of these chemical determinants, namely the carbon chain length, the type of functional groups and the number of fluorine atoms, generates an enormous number of different PFAS molecules with ample downstream applicability [7].

The most commonly detected PFAS types in groundwater and surface waters are PFOS (Perfluorooctane Sulfonic Acid), PFOA (Perfluorooctanoic Acid), PFNA (Perfluorononanoic Acid), and PFHxS (Perfluorohexane Sulfonic Acid). These long-chain PFAS (C>6) are used in applications such as firefighting foams and coatings [8,9]. Next to that, shorter chain compounds are frequently detected (PFBA, PFPeA, PFBS, etc). Trifluoroacetic Acid (TFA), the smallest PFAS molecule, is frequently detected as a breakdown product of other PFAS types. Measures are being taken to mitigate exposure to TFA as well [10]. The molecular structures of these PFAS types are illustrated below.



PFOS PFNA PFOA TFA

Figure 7. Commonly found PFAS types in surface water and groundwater.

(d) PFAS Water treatment technologies

(i) Current used technologies for PFAS removal only remove and incinerate

There are technologies available to remove PFAS from water streams, but these are primarily capture technologies, such as ion exchange resin (IXR) and granular activated carbon (GAC). While these methods can temporarily remove PFAS from water, the compounds are not degraded and persist in the environment, posing ongoing health risks. GAC and IXR are the most common methods for PFAS removal from groundwater and drinking water. Since PFAS are not destroyed by these methods, additional steps are required to eliminate the compounds. Much of the PFAS captured by IXR is stored until an effective destruction method becomes available [11]. In other cases, GAC and IXR particles are regenerated using chemicals.

The most common method for destroying PFAS in GAC and IXR is incineration. However, this requires extremely high temperatures (which is why PFAS are used in firefighting foams). This process is time-consuming, generates additional solid waste, and produces air pollution by transferring PFAS to another medium[2]. Incineration does not always completely break down all PFAS, leading to their presence in the flue gas and subsequent dispersion into the environment, potentially returning to water bodies [1].

Since capture technologies like GAC and IXR merely transfer PFAS from liquid to solid phases and require additional, environmentally harmful steps for further PFAS destruction, these technologies are excluded from consideration in this project.

(ii) Degradation and separation technologies still under development

Other types of technologies for PFAS removal include degradation and separation technologies. Degradation technologies break PFAS molecules into substances such as CO_2, H^+, and F^-. In contrast, separation technologies focus on dividing contaminated water streams into a PFAS-free stream and a concentrated PFAS stream. Although separation technologies do not destroy PFAS molecules, they are highly effective in concentrating the contaminated water into a smaller volume, which can enhance the efficiency of subsequent PFAS degradation processes [2].

Technologies capable of degrading PFAS molecules are still in development, but they have shown great promise in destroying them at lab-scale. Table 5 shows an overview of promising technologies and some of their characteristics (at lab-scale).

Table 5. Comparison of published PFAS destruction technologies in water media (derived from [11], detailing the active reagents for PFAS degradation, degradation efficiency (DE%), and energy consumption (kWh/m^3).

Technology	**Active reagents**	**Degradation**	**Energy consumption (kWh/m^3)**
Electrochemical Oxidation	Hydroxyl radicals (·OH), reactive oxygen species	Up to 98%	1-100

Plasma	Electrons, ions, radicals	Up to 99%	1-20
UV-Photocatalysis	Hydroxyl radicals (·OH), electron-hole pairs	Up to 99%	1-100
Sonochemical Degradation	Hydroxyl radicals (·OH), cavitation bubbles	Up to 99%	200-3000
Supercritical Water Oxidation	Supercritical water	Up to 99%	>1000

Various lab-scale experiments were conducted using different types of water and a range of PFAS concentrations. Overall, all techniques demonstrated high efficacy in PFAS degradation. Among the methods tested, electrochemical oxidation, plasma treatment, and UV-photocatalysis showed the lowest energy consumption rates. Significant variation in energy consumption was observed, which can be attributed to differences in experimental setups, such as PFAS type and concentration, process conditions, and scale. This indicates that optimization is ongoing and highlights the importance of real-world prototype experiments.

Besides degradation efficiency and energy use, other factors, such as scalability, limitations, and economic feasibility, are crucial for evaluating the potential of PFAS degradation technologies. The following table summarises the main advantages and disadvantages of PFAS destructive technologies.

Techno-economic analyses will validate the economic viability of these technologies, comparing the designed process with current PFAS treatment (adsorption followed by incineration) and other water treatment technologies. Current emerging water treatment technologies for micropollutant removal have cost estimates ranging from €0.15 to €0.70 per cubic meter of purified water [2,12]. The process designed in this project is expected to align with this cost range, maintaining a similar order of magnitude for cost-effectiveness. A quick, rough calculation of the costs for the technology combination estimates that the cost ranges from €0.50 to €0.70 per cubic meter of purified water[1]. However, it should be noted that these estimates do not include process optimization.

Table 6. Summary of the main advantages and disadvantages of PFAS destructive technologies, based on findings from extensive literature studies [11,13].

Technology	Advantages	Disadvantages
Electrochemical Oxidation	• Effective for long-chain PFASs. • Efficient for high PFAS concentrations. • Very high removal and defluorization efficiency. • Operates at ambient temperature and pressure. • Low environmental impact. • Potentially low energy consumption.	• Inefficient for short-chain PFASs. • Expensive electrodes with reduced lifetime.

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[1] Based on a three-step technology cascade: nanofiltration (NF), electrochemical oxidation (EO), and biodegradation. EO energy consumptions listed in Table 5 (p15) are assumed, for a price of 0.15 €/kWh. Only further treatment of the NF concentrate is necessary, NF recovery is 50%, NF costs are 0.43 €/m^3, and biodegradation costs are negligible.

Plasma	Effective for both long-chain and short-chain PFASs. Efficient for high PFAS concentrations. Potentially low energy consumption.	Affects water pH, making it acidic. Can form short-chain PFASs.
UV-Photocatalysis	Low energy consumption. High defluorination efficiency for PFOA.	Low degradation efficiency for PFOS. Inefficient for sulfonic groups. Produces toxic intermediate products. Longer reaction times compared to other methods. Scaling up may be challenging.
Sonochemical Degradation	Effective for both long-chain and short-chain PFASs. Efficient for high PFAS concentrations.	High energy consumption. Not ready for scaling up.
Supercritical Water Oxidation	Effective for both long-chain and short-chain PFASs. Low environmental impact.	Not economically viable for large volumes. Affects water pH, making it acidic.

Table 7. Advantages and disadvantages of various emerging treatment technologies for the removal or degradation of PFAS (based on information from [14–17]).

Aspect	**Reverse Osmosis**	**Nanofiltration**	**Electrochemical Oxidation**	**Plasma**	**UV-Photocatalysis**	**Sonochemical Degradation**	**Supercritical Water Oxidation**	**Biodegradation**
Long chain PFAS degradation	0	0	++	+	+	+	+	0
Short chain PFAS degradation	0	0	0	+	0	+	+	++
Long chain PFAS removal	++	++	++	+	+	+	+	0
Short chain PFAS removal	++	+	0	+	0	+	+	++
Energy consumption	+	+	+	+	+	-	-	++
Costs	+	+	+	+	+	--	-	+
Scale-up	++	++	+	+	0	--	0	0
By-product formation	++	++	0	0	0	0	0	+
Quality produced water	0	+	+	0	+	+	0	+

Based on the data from the previous tables, the **following technologies have been selected** for further development and potential lab-prototype studies for PFAS removal:

- **Electrochemical Oxidation**: Chosen for its effectiveness, especially against long-chain PFAS, high removal efficiency, ability to operate at ambient temperature and pressure, the potential for low energy consumption and scalability. Despite the cost-intensive electrodes, this technology offers the potential for improving lifespan and cost-effectiveness through optimization in prototype studies.
- **Plasma**: Selected for its effectiveness against both long and short-chain PFAS, the potential for low energy consumption, and scalability. Challenges such as acidic pH in water can be addressed through appropriate treatment methods, making it suitable for prototype studies.
- **UV-Photocatalysis**: This technology was chosen for its potential low energy consumption and high defluorination efficiency for specific PFAS compounds. While it is less efficient for certain other groups, it can be highly effective when combined with other methods. Integrating a multi-step process could address its limitations and enhance overall PFAS removal efficiency.
- **Biodegradation**: This technology is selected for its potential in selective degradation of PFAS at mild conditions at low energy consumption. Although it is currently less advanced in development and scaling up than other technologies, its potential to become a crucial component in the overall technology chain is evident.
- **Reverse Osmosis and Nanofiltration**: While these membrane filtration technologies only separate PFAS from water, they can significantly enhance the overall treatment process's efficiency when combined with degradation technologies. By reducing the volume of water that

requires further treatment, these filtration methods make subsequent degradation processes more efficient and manageable.

Other technologies, such as sonochemical degradation, were not chosen due to drawbacks such as lower degradation efficiency for certain PFAS types, higher energy consumption, and challenges in scaling up. These technologies may require further research and optimization before being ready for large-scale application.

(e) Selected PFAS water treatment technologies for this project

A brief state-of-the-art overview of the selected technologies is provided below.

(i) Electrochemical oxidation (EO)

Electrochemical oxidation (EO), or anodic or electro-oxidation, is an advanced oxidation process (AOP) proposed for treating industrial wastewater, including persistent contaminants like PFAS. This technique involves two electrodes, an anode, and a cathode, connected to a power source [11].

Contaminants can be degraded through direct or indirect oxidation mechanisms. In direct oxidation, pollutants are adsorbed onto the anode surface, where they undergo electron transfer. In indirect oxidation, strong oxidizing species are formed with energy input and a supporting electrolyte, which interact with and degrade the contaminants [18]. Organic components can degrade to CO_2 and water. For PFAS compounds, which contain many carbon-fluorine bonds, degradation results in products that still contain fluorine but are less harmful than PFAS. Most degradation mechanisms proposed by scientists aim to break down PFAS compounds into CO_2, fluoride (F^-), and H^+.

The performance of the EO system, in terms of removal efficiencies (such as defluorination) and energy consumption, depends on various process parameters. These include the anode material, current density, electrolyte type, distance between electrodes, residence time, feed water composition (PFAS concentration and types, other compounds, and pH) [19,20].

EO treatment has shown removal efficiencies for long-chain PFASs between 70% and 99%, while short-chain PFASs are generally more resistant to degradation [11]. Many studies have been conducted on a lab scale using synthetic PFAS solutions, predominantly with PFOA and PFOS [21]. However, there is a lack of systematic investigations to assess removal efficiencies and energy consumption in real-life contaminated waters [20].

Mixtures of PFAS in water show different treatment efficiencies and reaction rates than individual PFASs in synthetic water [21]. Additionally, experiments have used varying concentrations of PFAS, ranging up to mg/L [20–22], while real contaminated water typically has low PFAS concentrations (range of ng/L) that are lower than those of other compounds present [23].

Advantages of EO include its operation at ambient temperatures and pressures and the absence of harsh chemicals. However, disadvantages include the inefficiency of degrading short-chain PFAS molecules, potential high energy consumption, and the cost of electrodes. The low concentrations of PFAS in real water streams also make EO less efficient [11].

Overall, EO shows promise for industrial wastewater treatment, but further research and development are needed to optimize the process, especially for real-world applications. The knowledge gap in EO involves further development for the degradation of PFAS, including prototype testing with real wastewater and integrating the technology into processes that can achieve synergistic effects with other technologies. These aspects will be addressed in this project.

(ii) Plasma

Plasma, the fourth state of matter, is characterized by a neutral ionized gas containing free electrons, ions, and photons generated by an intense electric field. Plasmas can be categorized into thermal (TP) and non-thermal (NTP) types. TPs are produced at high gas pressures, whereas NTPs, produced at lower pressures, consume less energy and are therefore more investigated as a technology for water treatment [24].

NTP can be applied in water treatments through various methods:

- Direct methods: Electrodes are immersed in water.
- Indirect methods: Electrodes are placed above the water surface.
- Bubbling methods: Plasma is produced in air bubbles injected into the water.

Various reactors and processes have been developed. NTP technologies show promise for removing persistent contaminants due to their ability to produce a range of reactive species with both oxidative and reductive properties. Despite extensive research, only a limited number of commercial NTP solutions are available, which report high removal efficiencies for various contaminants but have not been explicitly tested for PFAS. Although the energy efficiency of NTP technologies requires improvement, they demonstrate potential for effective water treatment.

Laboratory-scale experiments have successfully removed various PFAS types. The treatment achieved high removal efficiencies (>90%) for longer-chain PFAS in deionized water. However, lower removal rates were observed in real water samples (tap water and synthetic effluent), ranging from 8% to 50%, depending on the compound and the specific water matrix. These studies highlighted complex matrix effects significantly influencing degradation rates, revealing distinct mechanisms for different PFAS compounds [25]. Other lab-scale experiments showed that PFAS molecules could be degraded in ultrapure water and groundwater. Degradation in ultrapure water occurred faster, with higher removal efficiencies (40-99%, depending on PFAS type) compared to groundwater (35-85%), again highlighting the effect of the water matrix [26].

Tests with landfill leachate treatment resulted in a high PFAS removal efficiency of >99% for long-chain PFAS, although the removal of short-chain PFAS was less effective [27]. Similarly, tests with contaminated groundwater, particularly from sites with a history of fire-fighting foam usage, showed high degradation rates (>90%) for some types of PFAS (e.g., PFOS), while other PFAS types only showed degradations of ~20%. The formation of short-chain PFAS types was also observed, indicating incomplete defluorination. Additionally, experiments showed that degradation efficiency increased with increasing PFAS concentration [28].

This research underscores the potential of non-thermal plasma technology for treating PFAS-contaminated water while emphasizing the need for further optimization to enhance removal efficiencies, particularly for shorter-chain PFAS and in varied water conditions [25].

The knowledge gap in NTP involves further development for the degradation of PFAS, including prototype testing with real wastewater and integrating the technology into processes where it can achieve synergistic effects with other technologies. This project will address these aspects.

(iii) UV-photocatalysis

In ***photocatalysis***, chemical reactions are accelerated in the presence of both a catalyst and light. Various catalysts and types of light can be used, with the type of light determined by its wavelength. ***Ultraviolet (UV)*** light is frequently employed in water treatment applications, making it a suitable focus for further exploration in this project.

UV light is already used in water treatment for disinfection [29]. Recently, research has been conducted to determine if UV light can also degrade contaminants, such as micropollutants and PFAS. Laboratory experiments aimed at degrading PFAS molecules using UV light have shown that mere exposure to UV radiation is insufficient, achieving only a 17% breakdown of PFAS. It is noted that the wavelength of UV light plays a crucial role in determining the degradation efficiency of PFAS molecules [30].

The use of UV in photocatalysis for degrading contaminants is well-studied, especially for the degradation of micropollutants in wastewater streams [31,32], although studies specifically targeting PFAS are still in development. TiO_2 is the most commonly used catalyst in these studies due to its outstanding activity, photochemical stability, and low cost. Research has shown that UV-photocatalysis can break down micropollutants, such as pharmaceuticals, dyes, and industrial components, with TiO_2 catalysts achieving up to 99% degradation. However, while these processes primarily target breaking C-H and C-O bonds, the challenge with PFAS lies in breaking the much stronger C-F bonds.

Lab-scale experiments have shown that using TiO_2 as a catalyst and UV light can degrade PFAS molecules. The degradation varies depending on the type of PFAS, with higher degradation rates (>80%) typically observed in longer-chain PFAS molecules [33]. Short-chain PFAS degrade more slowly under UV-photocatalysis [34]. Other experiments using TiO_2 photocatalysis with UV showed degradation rates ranging from 45% to 85% [35].

Other research has focused on combining UV with additional techniques to enhance PFAS degradation. These techniques include adding chlorine or peracetic acid, which improve molecule breakdown but require the addition of chemicals. Photocatalysis is particularly attractive as it does not consume or use chemicals [36].

UV photocatalysis is an emerging technology. UV-TiO_2 is still in the development phase, where optimal process conditions are being investigated. While it is currently not as advanced as plasma or electrochemical oxidation, it holds potential as a cost-effective technology that can complement a range of other treatment methods. The current knowledge gap in UV photocatalysis involves further development for the degradation of PFAS, including prototype testing with real wastewater and integrating the technology into processes where it can achieve synergistic effects with other technologies. This project will address these aspects.

(iv) Biodegradation

Recent studies have identified several microbial strains capable of partially degrading PFAS, including *Acidimicrobium sp.*, *Pseudomonas sp.*, and *Desulfovibrio sp.[37,38].* However, these strains generally exhibit very slow degradation rates and often result in incomplete mineralization, leading to the formation of less harmful but still persistent intermediates.

Complete microbial degradation of long-chain PFAS molecules to harmless metabolites is rather challenging. However, conversion of smaller-chain PFAS or derivatives resulting from other degradation technologies seem to be more promising. An example is the reported degradation of fluorinated acetic acid. These fluorinated organic acids are often byproducts of industrial processes and the breakdown of fluorinated compounds. Microbial defluorination and degradation of small PFAS derivatives such as PFOA, TFA and DFA has been reported [39–41]. Improved conversion might be obtained by adaptive laboratory evolution (ALE) has the potential to improve strains by natural mechanisms.

ALE is a technique used in microbiology and biotechnology to evolve microorganisms under controlled laboratory conditions to enhance specific traits or adapt to particular environments. In ALE, a microbial population is continuously cultured over many generations, typically under selective pressure, such as exposure to a toxic compound, limited nutrient availability, or extreme environmental conditions. This selective pressure drives natural selection, allowing for the survival and proliferation of mutants with beneficial adaptations. Over time, the microbial population accumulates genetic mutations that confer advantages in the given environment. These evolved strains can then be isolated, and their genetic changes analyzed to understand the mechanisms of adaptation. ALE is widely used to improve microbial strains for industrial applications, such as biofuel production, bioremediation, or the synthesis of valuable chemicals, and to study evolutionary processes in real-time. Here, we want to apply ALE for degradation of fluorinated acetic acid and other small-chain PFAS derivatives.

(v) Membrane filtration

Membrane filtration technologies, specifically ***nanofiltration (NF)*** and ***reverse osmosis (RO)***, are effective in separating and concentrating per- and polyfluoroalkyl substances (PFAS) from water streams. These technologies use semi-permeable membranes under pressure to selectively retain dissolved solids, micropollutants, and contaminants based on their molecular size and charge [42].

NF membranes operate at the nanometer scale, effectively capturing molecules with molecular weights typically between 200 and 1000 Daltons, which includes most PFAS molecules. RO membranes, with even smaller pore sizes, enhance selectivity by retaining even smaller substances, including monovalent ions [42].

By concentrating PFAS into a smaller volume, NF and RO do not degrade the substances but rather prepare them for subsequent treatment. This concentrated PFAS stream can then be treated more efficiently using electrochemical oxidation and plasma technologies, which perform better at higher PFAS concentrations [43].

Studies have underscored the effectiveness of NF and RO in treating PFAS-contaminated water, achieving high retention rates for both long and short-chain PFAS compounds [44]. Pilot studies, such as those conducted in Andijk using NF membranes in surface water from the IJsselmeer, demonstrated PFAS rejections ranging from 70% to 100%, with higher retention rates observed for longer-chain PFAS compounds [45]. Similarly, laboratory experiments using spiked PFAS components or synthetic water have shown that NF and RO achieve high PFAS rejections. NF achieved PFAS rejections ranging from 93% up to >98% [46,47], while RO achieved PFAS retentions exceeding 99% in controlled environments. [48,49].

NF and RO technologies are well-established globally for water purification, but their application to PFAS treatment is relatively new. Ongoing research focuses on optimizing membrane performance under diverse operating conditions and water matrix complexities to improve PFAS removal efficiency across a broader range of contaminants. These advancements are crucial for scaling from laboratory experiments to pilot studies and ultimately to full-scale implementation in environmental remediation efforts [50].

The current knowledge gap for NF and RO technologies lies in understanding their performance in real wastewater conditions and developing integrated processes that enable further degradation of PFAS in the concentrated streams. The PFASE-OUT project will address these aspects.

(f) PFAS Detection and screening

(i) Analysis of water quality by monitoring contaminants

Water quality analysis is time-consuming, and a cumbersome task requiring manual laboratory analysis. Therefore, water treatment facilities would benefit greatly from on-site monitoring tools that provide real-time information, interpretation and water quality alarming [51]. Analytical and chemical analysis is typically applied to monitor drinking water quality [52]. In addition, numerous biosensor methods have been developed that use specific ligands to detect single or some contaminants. Examples of ligands used are antibodies, aptamers, and molecularly imprinted polymers (MIPs) [53,54]. In recent years, online biomonitoring methods that employ living cells (in vitro) or organisms (in vivo) which shows a sensitive cellular, behavioural, or physiological response to stressors such as toxic pulses, have gradually become available [55,56]. These so-called Effect-Based Methods/Tools (EBM/EBT) or Effect-Based Monitoring bioassays are increasingly investigated, especially since these assays target groups of pollutants [57–60]. EBMs are indicative of specific endpoints, i.e., a measurable biological event that indicates an effect relevant to human and/or ecological health [61]. In addition, EBMs can detect the mixture effects of all active known and unknown chemicals in a sample, which cannot be addressed by chemical analysis alone [62]. Moreover, these methods are risk-scaled with more potent chemicals eliciting a stronger response than less potent chemicals when present at similar concentrations.

However, due to difficulties in maintaining a healthy status of living organisms and cells over a prolonged period of time and in combination with the laborious culturing of cells, their application for continuous monitoring purposes has been challenging. By combining receptors and other proteins that are involved in the EBT bioassays with the advantages of biosensor methods it appeared to be possible to develop tests that are not dependent on living organisms or cells and at the same time will be broadly recognizing a whole group of contaminants [63,64].

(ii) PFAS molecules - risks and monitoring

Most PFAS monitoring currently takes place using field sampling followed by chromatographic analytical methods, which are laboratory-based and are very costly when used to monitor PFAS in the environment [65]. These methods require a database with technique-specific data per PFAS molecule, which is almost impossible given the large number of compounds. At the moment, only a small part of all PFAS molecules can be detected analytically.

To overcome such issues, and to support obtaining robust data on the concentrations and identities of PFAS present, WFSR has developed a workflow for analysis of PFAS in water [66]. The comprehensive toolbox allows for the reliable analysis of the legacy PFAS and short chain PFAS, including trifluoroacetic acid (TFA), which is generally found in larger concentrations and increasingly recognised as a problem-compound. For analysing the total spectrum of PFAS (short and longer chains species, and potential degradation products) the combination of combustion ion chromatography (CIC) and liquid chromatography-high resolution mass spectrometry (LC-HRMS) will be used, providing answers on (i) the total mass of PFAS present in a sample and (ii) the identity of unknown PFAS, such as potentially formed degradation products. LC-HRMS was previously successfully applied by WFSR to surface water for identification of unknowns [67]. If appropriate, the total oxidisable precursor assay (TOPA) can be applied.

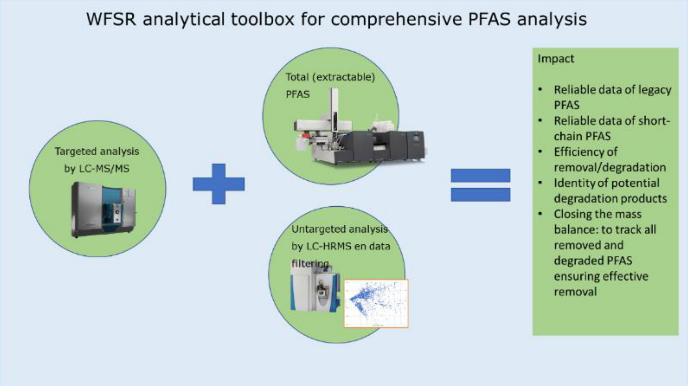

Figure 8. WFSR analytical toolbox for comprehensive PFAS analysis.

Other analytical instruments are used in conjunction with chromatographic techniques for detecting both target and non-target analytes at a lower level of detection (LOD). Nano-enabled sensors are an emerging technology that could be developed to enable low-cost, portable methods for the remote detection of PFAS species on-site in the future [68]. These authors indicate that the development of new sensors and technologies for PFAS detection should be focused on objectives such as field test device (portable and capable of in situ PFAS analysis), rapid analysis (detecting PFAS at its source in time to take immediate action; laboratory results for remote sites can take a week or more to arrive) and continuous monitoring of a polluted site (ensuring compliance with regulatory standards by monitoring soil, water, and wastewater remediation processes). It is noted that none of the monitoring studies reviewed in this study employed an in-situ methodology to quantify PFAS, and instead relied on laboratory equipment for PFAS quantification. Consequently, deployable devices are still in the experimental stage. However, most experimental studies claim potential for in situ or on-site application but are still conducted in laboratories.

(iii) Background of the new screening assay

Mechanistically, the toxic effects of PFASs are primarily mediated by their binding to proteins, nuclear receptors, and membranes [69,70]. The basic idea of the new screening assay relies on the observation that *in vivo*, PFAS compounds interfere in the binding of the endogenous compounds to their transport/binding proteins. Examples of such endogenous compounds are thyroid hormones and fatty acids.

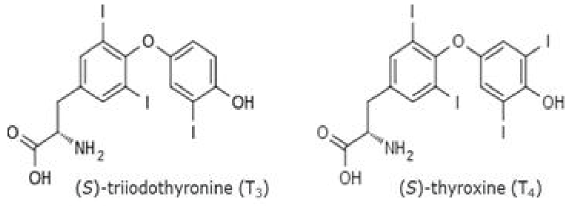

Figure 9. Thyroid hormones T3 and T4.

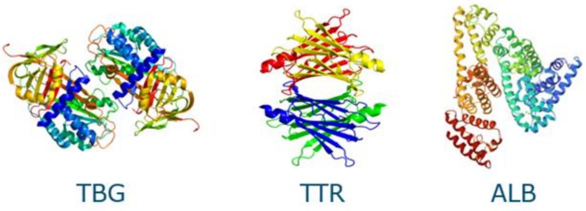

Figure 10. Proteins transporting the thyroid hormones T3 and T4 in the blood: thyroxine binding globulin (TBG), transthyretin (TTR) and albumin (ALB)

In blood thyroid hormones T3 and T4 (T4 more specifically; see Figure 9) are transported by some specific proteins. More than 99.8% of thyroid hormone circulating in blood is bound firmly to three plasma proteins, thyroxine-binding globulin (TBG), transthyretin (TTR), and albumin (ALB) [71,72]. Of these proteins (Figure), TTR is the only one passing the blood-brain-barrier and the placenta-barrier. From a toxicological perspective this makes TTR the most important binding protein. However, quantitatively, TBG is the most important; more than 70% of the total protein-bound hormone (both T4 and T3) is attached to TBG. About 10%–15% of circulating T4 and 10% of circulating T3 is bound to TTR and nearly equal amounts are bound to albumin. TBG concentration in plasma (16-24 mg/L) is only 6% that of TTR (100-400 mg/L) and less than 0.1% that of ALB (35-50 g/L). Consequently, TBGs affinity for both T4 and T3 is much higher than that of the other proteins.

Interference of T4 binding to TTR was shown in a publication that addressed the potential toxic effects of PFAS compounds [73] Ouyang *et al*. [74]transferred the radio-ligand thyroxine-transthyretin (T4-TTR) binding assay used in this study into a microtiter plate high-throughput fluorescence assay by using FITC-labelled T4. The TTR-binding assay involved the incubation of a possible T4 competitor with a fixed amount of FITC-T4 and TTR. After separation from free, remaining FITC-T4-compound, the fraction of FITC-T4 that bound to TTR was measured. In addition to direct measurement of fluorescence the same principle can be applied to a fixed amount of unlabelled T4 of which the remaining fraction bound to TTR is detected by a subsequent incubation with the TRβ CALUX bioassay, a reporter gene cell assay expressing the thyroid receptor β [75,76]. For polybrominated compounds it was shown that, in addition to TTR, they compete for binding of thyroid hormone to the most important thyroxine binding protein in human blood, i.e. TBG [77]. A fluorescein−thyroxine (T4) conjugate was designed, synthesized, and characterized as a site-specific fluorescence probe for competitive binding assays with TTR and TBG.

Fatty acid-binding proteins (FABPs) are members of the intracellular lipid-binding protein (iLBP) family and are involved in reversibly binding intracellular hydrophobic ligands and trafficking them throughout cellular compartments, including the peroxisomes, mitochondria, endoplasmic reticulum and nucleus. FABPs are small, structurally conserved cytosolic proteins [78]. Two examples of this protein family are shown in Figure 11. FABPs have broad specificity, including the ability to bind long-chain (C16-C20) fatty acids, eicosanoids, bile salts and peroxisome proliferators. To date, nine FABP protein-coding genes have been identified in the human genome.

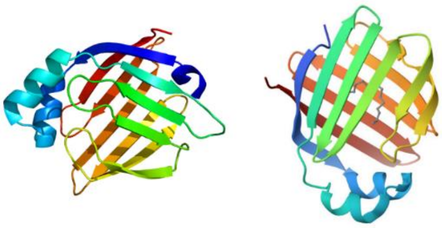

Figure 11. Human Heart Fatty Acid Binding Protein (H-FABP) (left) and human Liver Fatty Acid Binding Protein (L-FABP) in complex with a molecule palmitic acid (right).

PFAS molecules compete for binding to FABPs with fatty acids and other hydrophobic ligands. Yang and co-workers developed an experimental method for nontargeted analysis (NTA) of PFAS molecules binding to human L-FABP from environmental water mixtures[79]. To achieve this, they implemented a method by employing size-exclusion chromatography-co-elution and NTA to screen L-FABP ligands with high selectivity. In aqueous film forming foams-contaminated river waters 39 chemicals were discovered as new L-FABP ligands.

A fluorescence-based biosensor for the rapid detection of PFAS based on human liver fatty acid binding protein (L-FABP) was designed and produced by Mann *et al*. [80]. Introduction of solvatochromic fluorophores within the ligand binding pocket of L-FABP allowed for intrinsic detection of PFAS compounds. The acrylodan conjugated variant appeared capable of detecting PFOA, PFOS, and PFHxS in PBS with LODs of 112 ppb, 345 ppb, and 1.09 ppm, respectively. The protein-based sensor was also capable of detecting these contaminants at similar ranges in spiked environmental water samples.

The examples of thyroid hormones and fatty acids binding proteins show the feasibility of using these proteins as ligands to detect PFAS molecules.

(iv) New method to screen for PFAS molecules

Based on the literature mentioned above and literature describing other proteins that bind PFAS molecules it is proposed to develop a new, initial PFAS screening method that, in principle, would be suited to monitor PFAS molecules from various classes (Figure 6). Such a screening assay could be applied to samples from a range of sources such as human bodily fluids, food, and feed samples, and environmental (soil and water) samples.

An important step in the detection procedure will be sample pretreatment. This should be a simple method that low-skilled people can perform, it should be a fast method that does not require sophisticated apparatus, and it should be applicable to a vast range of PFAS molecule classes. Thereto, the PFAS binding proteins described above and others mentioned in literature will be used to cover the binding of as many PFAS molecules as possible. Specific proteins such as the thyroid hormone binding TTR and the fatty acid binding FABP will be supplemented with proteins such as HSA and BSA. The method will have a competitive format in which a selection of PFAS molecules, labelled to e.g. a fluorophore, enzyme, or nanoparticles, will be used as detector (Figure 12). One of the goals in development will be to find the most efficient labelled PFAS molecule for each binding protein. Small volumes of these binding proteins will be bioprinted in the wells of microtiter plates that have a cellulosic bottom. Thereto, a ultra-low volume arrayer will be used (sciFLEXARRAYER S3) that can print droplets down to 300 picoliter of various concentrations of each of the binding proteins. These ultra-low volumes guarantee that the method will be very inexpensive, an important requirement for an initial screening method.

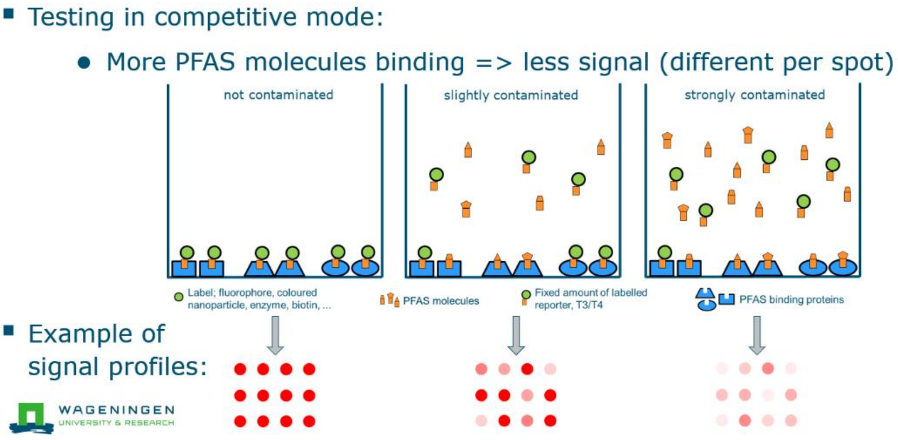

Figure 12. Principle of the new method in the well of a microtiter plate in which the binding of labelled PFAS molecule to the various binding proteins is competed by unknown PFAS molecules in the sample.

Using microtiter plates with a cellulosic bottom opens the possibility to apply vacuum to flow reactants through the layer with immobilised binding proteins to increase interactions with the free compounds, to increase sensitivity and to speed up test results. In addition, filtration by applying a vacuum would enable the use of bigger sample volumes, which would increase sensitivity of the test as well.

Per protein spot the signal of the (remaining) protein-bound labelled PFAS molecules will be detected by an automated Microarray Plate Reader such as the Fluorowatcher and the Colorwatcher image readers from Bioscience Media (Figure). These readers read a full plate in 5 minutes, i.e. by taking an image of each well followed by processing the pixel intensities of each spot. The user can adapt the reader output in the software package delivered with the readers. Signal profiles will be analysed by an artificial intelligence-supported algorithm based on a profile database. Building this database will be part of the development as well.

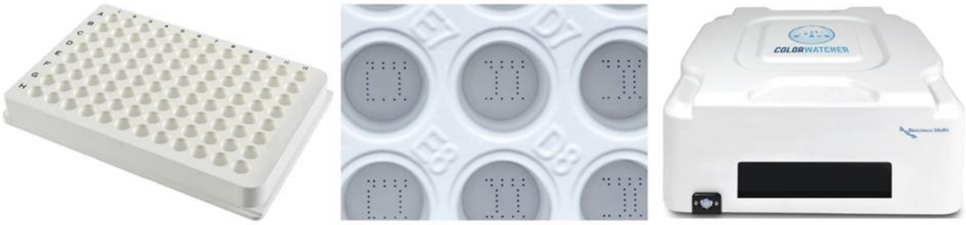

Figure 13. Microtiter plate (left), a microarray of spots in wells (middle), and an automated microtiter plate image reader from Bioscience Media that returns results in five minutes (right).

The new test procedure will contribute to the KRW challenges in that it will simplify the detection of PFAS molecules, enable the simultaneous testing of many samples and substantially reduce the time needed for testing. In addition the method is in line with the very recently launched technical guidelines for monitoring PFAS according to the revised Drinking Water Directive (European Commission).

In addition to application in a laboratory, the test can potentially be applied in the back of a truck or a van as well. This would enable on-site testing and the immediate availability of results.

(g) What knowledge gaps exist, and how does your project address them?

While considerable information exists regarding the performance and design of individual technologies for the degradation or separation of PFAS from water streams, notable knowledge gaps remain in several key areas:

- **Incomplete degradation**: No current technology can completely degrade all PFAS to achieve full destruction. This gap must be addressed in future research [81]. Many degradation technologies can break down PFAS molecules, but this often results in incomplete defluorination and the formation of byproducts such as short-chain PFAS molecules.
  This project aims to further investigate the possibilities of promising degradation technologies and design a process comprising a chain of technologies that complement and enhance each other to degrade PFAS completely.
- **Combination of technologies**: The exploration of combined technologies is limited. Specific techniques can enhance others' efficiency [13]. For example, membranes can concentrate PFAS, making subsequent treatments with electrochemical oxidation (EO) and plasma more effective. Additionally, membrane technology allows for the treatment of only the concentrated fraction of water, reducing the overall volume requiring further treatment.
  This project will focus on developing a comprehensive PFAS degradation process by leveraging the synergistic effects of combined technologies.
- **Scaling up**: There is a lack of literature on full-scale and prototype/pilot-scale setups for PFAS removal. More attention is needed to optimize functional aspects during scaling up. Most research is conducted at the laboratory scale under ideal conditions, and these methodologies require validation in real-world applications with long-term studies [82].
  This project will address this gap by initially understanding individual technologies with synthetic water in Phase I and testing and evaluating the process using actual wastewater or groundwater from project partners in a prototype setup during Phase II.
- **Techno-economic and environmental analysis**: Since much of the research on PFAS removal and degradation is conducted at the lab scale, the focus has primarily been on removal efficiencies rather than on the economic aspects, including operational expenditures (OPEX), capital expenditures (CAPEX), and the carbon footprint. This project will address this knowledge gap by performing a techno-economic and environmental analysis and comparing the results with benchmark technologies such as incineration.
- **On-site PFAS detection and monitoring**: Current methods for PFAS detection are predominantly laboratory-based, costly, and time-consuming, making them unsuitable for real-time, on-site monitoring [5].
  This project aims to develop a low-cost and high-throughput screening method for on-site PFAS detection. By using various PFAS-binding proteins and integrating Effect-Based Monitoring (EBM) and bioassays, we will create a rapid screening method to detect a broad range of PFAS molecules.

(h) What will this project deliver in concrete terms?

At the end of the project, we aim to provide:

- **New insights into PFAS occurrence**: Detailed data on PFAS in effluents and groundwater, including types of compounds, concentrations, variations between locations, and seasonal changes across different water streams.
- **Technology evaluation**: This involves evaluating the effectiveness of selected water treatment and monitoring technologies using real wastewater samples.
- **Rapid detection technologies**: A newly developed effect-based method for initial screening of PFAS molecules.

- **Evaluation of a comprehensive process**: An assessment of a new process for the complete removal and degradation of PFAS, including technical performance indicators (e.g., removal efficiencies), and evaluations of economic, environmental, and social impacts.
- **Technological solutions**: Practical solutions for the on-site treatment of PFAS-contaminated water streams, such as effluents and groundwater.
- **Increased Technology Readiness Level (TRL)**: Advance PFAS removal technologies to a higher TRL, demonstrating their effectiveness and reliability in real-world scenarios.
- **Comprehensive report**: A detailed report consolidating all project findings, insights, and recommendations.

Annex 3: Comprehensive multi-year work plan

The project will be carried out in three phases. Phase I involves "Technology and Case Evaluation," Phase II is the "Lab-Prototype Phase", and Phase III focuses on "Techno-Economic Evaluation”.

(i) Phase I: Technology and Use Case Evaluation

Phase I is exploratory and aims to:

1) Understand the current technologies for monitoring and removing PFAS from water and assess PFAS presence in different water sources
2) Evaluate and compare the performance of these technologies using standard synthetic discharge water
3) Advance emerging PFAS treatment and monitoring technologies to higher Technology Readiness Levels (TRLs)

Tests in this phase will be conducted using standard (synthetic) wastewater to assess the impact of technologies on PFAS. In real water sources, other contaminants (such as TOC, COD, and turbidity) may also affect the performance of these technologies. This will be addressed in Phase II during the Process Design (WP 6).

WP 1. ***Characterization of water streams of use cases***

Determining the types and concentrations of PFAS in various water streams is important. This work package, therefore, focuses on characterizing water streams contaminated with PFAS (**Task 1.1**). These streams originate from project partners who handle different water streams, such as WWTP effluents, industrial effluents, groundwater and surface water used for drinking water preparation.

The characterization will include other properties of the water streams, such as TOC, conductivity, ion composition, turbidity, pH, and temperature. The total flow rate (m^3/h) is also crucial for scaling-up considerations. Understanding these properties is essential for the project's progression, as they can significantly impact the performance of technologies aimed at removing and degrading PFAS.

The project aims to produce water suitable for use or reuse. Therefore, we will gather information from our partners regarding the quality specifications necessary to meet the requirements for water reuse. These specifications may include legislation or regulations governing water discharge or drinking water standards.

Partners involved: WFBR (lead), WFSR, Smurfit Kappa, Chemours, VNCI, VIG, Attero, Boskalis, Het Waterlaboratorium

Deliverables:

- *D1.1: Characterization of water streams.*

WP 2. ***Evaluation and testing of treatment technologies***

This work package (WP) aims to experimentally evaluate promising water treatment and monitoring technologies for the separation and degradation of PFAS on a lab scale. Technologies provided by project partners, including concentration methods such as nanofiltration/reverse osmosis and degradation techniques like plasma and UV, will be assessed to determine their performance, efficiency in PFAS removal, energy consumption, and scalability.

The first step involves creating a composition for synthetic PFAS water based on input from WP 1 (**Task 2.1**). Next, a plan will be developed for testing the treatment technologies (**Task 2.2**). The impact of critical operational parameters, such as pressure, temperature, and feed flow rate, on the efficiency of PFAS removal or degradation will be examined, with specific parameters provided by the technology providers.

Selected technologies will be tested using a synthetic water feed stream that simulates typical PFAS-contaminated water, ensuring relevant and consistent test conditions. This testing will incorporate outcomes from WP 1 and existing literature. WFBR will conduct the experiments (**Task 2.3**), while WFSR will perform the PFAS analysis to determine the efficiency of PFAS removal and characterisation of PFAS degradation products, using their state-of-the-art analytical toolbox combining CIC, LC-high resolution MS and targeted LC-MS/MS analysis.

Key performance indicators (KPIs) will be identified and quantified, such as PFAS removal efficiencies, energy use, and potential byproduct formation. These results will inform the development of a complete process to degrade PFAS in WP 6.

Partners involved: WFBR (lead), WFSR, Bluecon, AquaTech, (echemtech, Diaccon)

Deliverables:

- *D2.1: Composition of synthetic water*
- *D2.2: Test plan with parameters and conditions for each technology*
- *D2.3: Updates on outcome of lab tests, including key performance indicators such as PFAS removal, suggestions for technologies to be used in a hybrid process for full degradation of PFAS, and scale-up possibilities.*

WP 3. Development and testing of Electrochemical Oxidation

In this work package (WP), an electrochemical oxidation setup will be designed based on an existing system for the formation of hydrogen peroxide, reactive oxygen, and OH-radicals, owned by WFBR (developed in Green Oxidants project[2]).

A plan will be developed for testing the electrochemical oxidation technology for PFAS degradation (**Task 3.1**). This plan will include critical parameters to be investigated, such as electrode type, electrolyte, and current density, to achieve the most efficient design and operational conditions.

The setup is suitable for prototype testing. WFBR will conduct the experiments, while WFSR will carry out the PFAS analysis using their analytical toolbox. Key performance indicators (KPIs), such as PFAS removal efficiencies, energy use, and information about potential byproduct formation, will be identified and quantified (**Task 3.2**). These results will contribute to developing a complete process to degrade PFAS in WP 6.

The synthetic water feed stream, developed in WP 2, will also be used in this work package to simulate typical PFAS-contaminated water, ensuring relevant and consistent test conditions.

Partners involved: WFBR (lead), WFSR, echemtech, Diaccon

Deliverables:

- *D3.1: Test plan with parameters to be investigated.*

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[2] https://www.wur.nl/en/project/electrochemical-production-of-green-oxidizing-agents.htm

- *D3.2: Updates on the outcome of lab experiments, including key performance indicators such as removal of PFAS types and suggestions for use in a tech-chain for full degradation of PFAS and scale-up possibilities.*

WP 4. Development and testing of Microbiological Degradation of short-chain PFAS

Explore and develop microbiological processes for the degradation of PFAS molecules and PFAS derivates as products from other conversion technologies used in this project. Within this work package, conversion of PFAS molecules, and their conversion products, will be monitored with the analytical toolbox, as well as with in-line monitoring developed in WP5.

The first focus will be on the proven biodegradation of difluoro acetic acid and the extension of this conversion capacity to TFA. We will investigate the microbial degradation and investigate parameters and conditions for increased efficiency for TFA degradation (**Task 4.1**). Subsequently, we will explore the microbial degradation of other PFAS and PFAS derivatives originating from other treatment technologies as investigated in WP2 and WP3 (**Task 4.2**).

Adaptive laboratory evolution is selected as a key technology to improve strains with biodegradation activity (**Task 4.3**).

Partners involved: WFBR, WFSR

Deliverables:

- *D4.1:* Report on the microbial conversion of TFA
- *D4.2:* Report on the potential of microbial degradation for selected PFAS molecules and derivatives
- *D4.3:* Report on the strain improvement (using ALE)

WP 5. Development and testing of PFAS-screening method

WP 5 is on developing and applying an Effect-Based method for initial screening of PFAS molecules and will consist of several tasks. A selection of representative PFAS molecules will be labelled with a fluorophore, and the resulting conjugates will be used as reporter compounds (**Task 5.1**).

The synthesis of these compounds will require covalent chemical interaction and purification to separate the compound from the unlabelled PFAS molecules and the free fluorophore. Several PFAS binding proteins (at least 6) will be printed onto the cellulosic bottom of the wells of microtiter plates by using an array printer that can print droplets down to 300 picolitre (**Task 5.2**).

The immobilised proteins can bind one or several reporter compounds that will be added to the wells in fixed amounts. To screen for PFAS molecules samples, from 100 microliter up to a millilitre, will be filtrated through the cellulosic bottom by vacuum (**Task 5.3**).

Depending on the PFAS molecule(s) present one or several proteins will bind these molecules, leaving fewer binding sites for reporter compounds that will be incubated in de wells in the next step. If PFAS molecules from the sample will have bound, less reporter compounds will be immobilised by the proteins and the signal(s) of the various protein spots will show decreased signals. The signal spot profile will be compared to a database built during the project by incubating 1) single PFAS molecules, 2) mixtures of 2 and 3 PFAS molecules and 3) complex mixtures. Building this database and developing an algorithm that interprets signal profiles will be the subject of a separate task (**Task 5.4**).

Artificial Intelligence will be used to improve the algorithm's interpretation. To enable testing real samples, dedicated pretreatment protocols should be developed (**Task 5.5**). Thereto, protocols will be optimised for several water sources.

In the next step, mixtures of PFAS molecules will be spiked in water samples from real sources of background PFAS levels (**Task 5.6**). This will yield initial information on sample matrix influences on test performance.

Finally, real samples from various sources will be collected and tested in the screening method (**Task 5.7**). A confirmatory analytical technique will also detect PFAS molecules in these samples.

If successful, standardisation of the full test procedure, including the screening method, will be started, preferably in close collaboration with a company willing to commercialise the test (**Task 5.8**). Standardisation includes parameters such as the secured and long-term availability of reagents and disposables, the commercial production of the full test and the support with respect to the software needed to process and translate test signals into meaningful results.

Partners involved: WFBR (lead), BioDetection Systems, Forever Analytical, Het Waterlaboratorium

Deliverables:

- *D5.1: PFAS molecules selection and conjugation to a fluorophore*
- *D5.2: Protocols for each of the binding proteins established*
- *D5.3: Confirmation test principle of PFAS molecules binding to immobilised proteins*
- *D5.4: Database of signal profiles and an algorithm to interpret results*
- *D5.5: Sample pretreatment protocols for at least three water sources*
- *D5.6.: Tests spiked PFAS mixtures in samples from real water sources*
- *D5.7: Tests PFAS containing real samples with screening method, confirmed by a conventional analytical technique*
- *D5.8: Update on standardisation of the PFAS screening method*

(j) Phase II: Lab-Prototype Phase

Phase II focuses on designing a process for complete PFAS removal and degradation and demonstrating its practical application. The objectives are to identify synergies between separation and degradation technologies and evaluate the integrated process with real water samples in a lab-prototype, advancing the technology's readiness level (TRL). This phase will work with contaminated waters from project partners, such as groundwater, surface water or effluents, where additional contaminants (e.g., TOC, COD, turbidity) may affect the technologies' performance. Consequently, the process design will not only include PFAS degradation technologies but also incorporate pre-treatment steps to address and remove these other contaminants.

WP 6. Lab-prototype integration

Phase II begins with designing a process to eliminate PFAS from a water stream, ensuring complete removal and degradation. This design will leverage the characterization of water streams and the key performance indicators (KPIs) for various technologies identified in Phase I. The process will consist of a sequence of different technologies, each contributing to the overall removal and degradation of PFAS.

Additionally, the design will account for other contaminants such as TOC, COD, and turbidity in the real water samples. These additional contaminants may impact the performance of PFAS removal technologies. Therefore, the process will include pre-treatment steps to manage and mitigate the effects of these contaminants, ensuring the overall effectiveness of PFAS removal.

First, input parameters such as technology KPIs, feed water composition, and effluent quality demands will be chosen. Output parameters like mass balance, pressures, temperatures, and energy usage will also be determined (**Task 6.1**).

Next, one or more process designs will be developed using the selected software (**Task 6.2**). The design will be created using SuperPro or Excel sheets simulation software and performed by WFBR.

Partners involved: All partners (lead: WFBR)

Deliverables:

- *D6.1: Overview of input and output parameters for the designed process*
- *D6.2: Detailed process designs*
- *M6.1: Milestone: Process chosen to be worked out for prototype testing and techno-economic, environmental & social analysis.*

WP 7. Lab-prototype testing

The process will be practically tested by treating actual water streams. This will be conducted in a lab-scale prototype unit placed on-site or transporting real water to a test location.

To prepare for the lab-prototype phase, individual technology units will be gathered and set up for testing. The process will operate sequentially rather than as a single unit. In this setup, the effluent from one unit will be the influent for the next unit. This allows for the independent assessment of each unit's performance while evaluating the overall effectiveness of the entire process. A detailed plan outlining process conditions, sampling times, and other relevant parameters will be made (**Task 7.1**). This preparation will culminate in a lab-prototype phase planning and setup ready for use.

The designed process will then be tested at a selected real-life or test location (**Task 7.2**). This involves transporting real water to the test location if needed. Performance will be evaluated by collecting and analyzing data and samples from the individual units. The long-term data collected will be used to derive mass and energy balances and trace the flow of PFAS components throughout the integrated system. Additionally, factors affecting the energy consumption of the integrated system, such as feed water quality and product water quality, will be analyzed.

Partners involved: All partners (lead: WFBR)

Deliverables:

- *D7.1: Lab-prototype planning and setup ready for use.*
- *D7.2: Updates on the lab-prototype outcomes, including key performance indicators such as PFAS removal efficiency.*

(k) Phase III: Techno-Economic-Social-Ecological evaluation

In Phase III, the process developed in Phase II will be evaluated for its techno-economic, environmental, and social impact. The techno-economic evaluation will assess the costs of operational expenses (OPEX) and capital expenditures (CAPEX) for targeted PFAS removal efficiencies.

WP 8. Techno-economic-social-ecological impact assessment

A cost estimation for the integrated process will be developed using the output from WP6 and the KPIs from WP7, including CAPEX, OPEX, and energy use calculations (**Task 8.1**).

The environmental evaluation will analyse the process's carbon footprint and the quality of the treated water. An environmental analysis will be performed, focusing on the carbon footprint of the integrated process, and assessing its overall environmental impact (**Task 8.2**).

The social impact evaluation will assess stakeholder acceptance and the broader societal impact of the developed PFAS degradation process. This will involve surveying various stakeholders, including industrial and drinking water companies, water boards, governmental entities, and technology providers, to measure their perceptions of the process's feasibility and acceptance (**Task 8.3**). The evaluation will focus on understanding stakeholder acceptance, regulatory compliance, and other societal factors influenced by the implementation of the process.

Finally, the techno-economic and environmental impacts of the developed process will be compared to benchmark technologies, such as incineration, and existing water treatment technologies for other micropollutants. The cost of these benchmark technologies typically ranges from €0.15 to €0.70 per cubic meter of purified water [14–16]. This comparison will evaluate the relative performance and benefits of the developed process (**Task 8.4**).

Partners involved: All partners (lead: WFBR)

Deliverables:

- *D8.1: Overview of CAPEX, OPEX, and energy use for new process*
- *D8.2: Overview of environmental impact the developed process*
- *D8.3: Summary of stakeholder perceptions regarding implementing the developed process.*
- *D8.4: Overview of comparison between techno-economic and environmental impact assessments of developed process and benchmark technology*

(I) Organization

WP 9. Dissemination and communication

In this work package, WFBR will provide periodic updates on the project, technical developments, and optimization outcomes to all partners through presentations or written reports. One of these updates will be a consortium meeting held at least twice a year in person or hybrid format.

Various channels, such as peer-reviewed journals and conferences, will be used to publish the project's findings and share knowledge with the scientific community and industry peers. Public relations activities, including media and social media outreach, will be utilized whenever possible to raise awareness of the project. Partners will also be encouraged to share findings within their networks.

Knowledge dissemination outside the consortium will only occur with the agreement of all partners and, if applicable, after filing patents to protect the newly generated intellectual property (IP). The final product of this project will be a comprehensive joint report on the research findings, technical performance data, economic analysis, environmental assessment, and lessons learned.

To ensure effective knowledge transfer, WFBR will document all knowledge transfer activities, including publications, presentations, and outreach efforts (**Task 9.1**).

A final comprehensive report summarizing the project's findings and insights will be compiled. This report will include a summary of performance indicators of technologies during the lab phase, performance outcomes from prototype tests, suggestions for process improvements, and a comparative analysis of the developed process versus current treatment methods, covering techno-economic, environmental, and social aspects (**Task 9.2**).

Partners involved: All partners (lead: WFBR)

Deliverables:

- *D9.1: Documentation of knowledge transfer activities.*
- *D9.2: Report detailing technology and process performance, improvement suggestions, and comparative analysis.*

WP 10. Project management and coordination

This work package aims to efficiently manage the project, maximize impact for all partners, reduce risks, and oversee the project's budget and financing. WFBR will lead the project and ensure effective communication, timely execution, and alignment with project milestones (**Task 10.1**). Specific responsibilities of this task include:

- Facilitating regular meetings.
- Managing resources.
- Resolving any issues that arise during the project.
- Ensuring all activities in the project are coordinated and aligned with the main goals.

A core team of researchers will handle the day-to-day execution of the research project and will meet more frequently. A steering committee, consisting of a representative from each knowledge and private partner, will ensure the project stays aligned with its goals, remains within budget, and adapts to changing circumstances. This committee will be formed during the kick-off meeting and will have update meetings at least twice a year.

Partners involved: WFBR

Deliverables:

- *D10.1: Meeting schedules and minutes, disseminated results and completed project reports.*

(m) Overview of deliverables

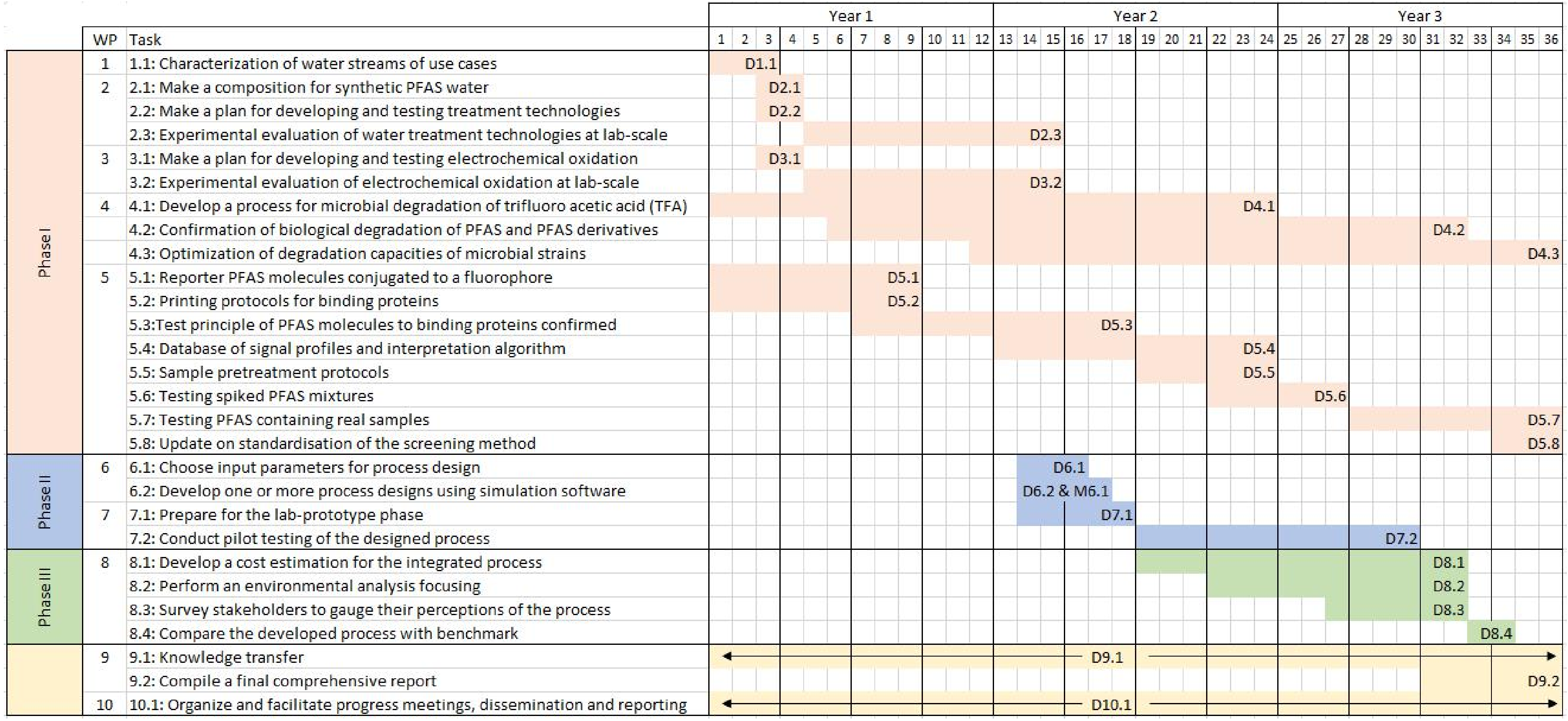
The following table shows the expected deliverables (D) and milestones for this project's different work packages (WP).

Table 8. Expected deliverables (D) and milestones for all work packages (WP) of this project.

Deliverables (D)	**Description**	**Deadline (Month)**	**WP**
Phase I: Technology and Use Case Evaluation			
D1.1	Characterization of water streams	M3	1
D2.1	Composition of synthetic water	M4	2
D2.2	Test plan with parameters and conditions for each technology from technology providers	M4	2
D2.3	Updates on the outcome of lab experiments	M15	2
D3.1	Test plan with parameters to be investigated for electrochemical oxidation (EO)	M4	3
D3.2	Updates on the outcome of lab experiments with EO	M15	3
D4.1	Process for microbial degradation of trifluoro acetic acid (TFA)	M24	4
D4.2	Evaluated process for biological degradation of PFAS and PFAS derivatives	M32	4
D4.3	Optimization of degradation capacities of microbial strains	M36	4
D5.1	PFAS molecules selection and conjugation to a fluorophore	M9	5
D5.2	Protocols for each of the binding proteins established	M9	5
D5.3	Confirmation test principle of PFAS molecules binding to immobilised proteins	M18	5
D5.4	Database of signal profiles and an algorithm to interpret results	M24	5
D5.5	Sample pretreatment protocols for at least three water sources	M24	5
D5.6	Tests spiked PFAS mixtures in samples from real water sources	M27	5
D5.7	Tests PFAS containing real samples with screening method, confirmed by conventional analytical technique	M30	5
D5.8	Update on standardisation of the PFAS screening method	M36	5
Phase II: Demonstration			

D6.1	Overview of input and output parameters for the designed process	M16	6
D6.2	Detailed process designs	M17	6
M6.1	***Milestone: process chosen for further testing and evaluation***	*M17*	6
D7.1	Lab-prototype planning and setup ready for use	M18	7
D7.2	Updates on the lab-prototype outcomes	M30	7
Phase III: Techno-Economic Evaluation			
D8.1	Overview of CAPEX, OPEX, and energy use for the developed process	M32	8
D8.2	Overview of the environmental impact of the developed process	M32	8
D8.3	Summary of stakeholder perceptions regarding implementing the developed process	M32	8
D8.4	Overview of the comparison between the techno-economic and environmental impact assessments of the developed process and benchmark technology	M34	8
Organization			
D9.1	Documentation of knowledge transfer activities	M36	9
D9.2	Final report	M36	9
D10.1	Meeting schedules and minutes, disseminated results, and completed project reports	M36	10

Figure 14. Multi-year schedule. Planning of tasks, deliverables (D) and milestones (M) for the PFASE-OUT project.



			Year 1												Year 2												Year 3											
	WP	Task	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
Phase I	1	1.1: Characterization of water streams of use cases	■	■	D1.1																																	
	2	2.1: Make a composition for synthetic PFAS water			■	D2.1																																
		2.2: Make a plan for developing and testing treatment technologies			■	D2.2																																
		2.3: Experimental evaluation of water treatment technologies at lab-scale					■	■	■	■	■	■	■	■	■	■	D2.3																					
	3	3.1: Make a plan for developing and testing electrochemical oxidation			■	D3.1																																
		3.2: Experimental evaluation of electrochemical oxidation at lab-scale					■	■	■	■	■	■	■	■	■	■	D3.2																					
	4	4.1: Develop a process for microbial degradation of trifluoro acetic acid (TFA)	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	D4.1												
		4.2: Confirmation of biological degradation of PFAS and PFAS derivatives						■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	D4.2				
		4.3: Optimization of degradation capacities of microbial strains												■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	D4.3
	5	5.1: Reporter PFAS molecules conjugated to a fluorophore	■	■	■	■	■	■			D5.1																											
		5.2: Printing protocols for binding proteins	■	■	■	■	■	■			D5.2																											
		5.3:Test principle of PFAS molecules to binding proteins confirmed							■	■	■	■	■	■	■	■	■	■	■	D5.3																		
		5.4: Database of signal profiles and interpretation algorithm													■	■	■	■	■	■	■	■	■	■	■	D5.4												
		5.5: Sample pretreatment protocols																			■	■	■	■	■	D5.5												
		5.6: Testing spiked PFAS mixtures																						■	■	■	■	■	D5.6									
		5.7: Testing PFAS containing real samples																												■	■	■	■	■	■	■	■	D5.7
		5.8: Update on standardisation of the screening method																																		■	■	D5.8
Phase II	6	6.1: Choose input parameters for process design														■	■	D6.1																				
		6.2: Develop one or more process designs using simulation software														■	■	■	D6.2 & M6.1																			
	7	7.1: Prepare for the lab-prototype phase														■	■	■	■	D7.1																		
		7.2: Conduct pilot testing of the designed process																			■	■	■	■	■	■	■	■	■	■	■	D7.2						
Phase III	8	8.1: Develop a cost estimation for the integrated process																			■	■	■	■	■	■	■	■	■	■	■	■	■	D8.1				
		8.2: Perform an environmental analysis focusing																						■	■	■	■	■	■	■	■	■	■	D8.2				
		8.3: Survey stakeholders to gauge their perceptions of the process																											■	■	■	■	■	D8.3				
		8.4: Compare the developed process with benchmark																																	■	D8.4		
	9	9.1: Knowledge transfer	◄	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	D9.1	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	►
		9.2: Compile a final comprehensive report																															■	■	■	■	■	D9.2
	10	10.1: Organize and facilitate progress meetings, dissemination and reporting	◄	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	D10.1	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	►

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Annex 2 - Background Included (and limitations on use)

Attero B.V.

As to Attero B.V**.**, it is agreed between the Parties that, to the best of their knowledge the following Background is identified and agreed upon for the Project. Specific limitations and/or conditions, shall be as mentioned hereunder:

Describe Background	Specific limitations and/or conditions for the Project	Specific limitations and/or conditions for exploitation
Attero can make available land for testing, no CAPEX investments considered.	-	-

This represents the status at the time of signature of this Consortium Agreement.

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Bio Detection Systems B.V.

As to Bio Detection Systems B.V., it is agreed between the Parties that, to the best of their knowledge the following Background is identified and agreed upon for the Project. Specific limitations and/or conditions, shall be as mentioned hereunder:

Describe Background	Specific limitations and/or conditions for the Project	Specific limitations and/or conditions for exploitation
BDS's proprietary TTR-TRbeta CALUX reporter gene assay for analysis of total PFAS activity, for comparison to newly developed biosensor-based assay. Use of this assay will mainly be performed by BDS, but in some (rare) cases a third party may obtain a limited user license for performing analyses at their own laboratory facilities Exploitation of background IP is exclusively for BDS		

This represents the status at the time of signature of this Consortium Agreement.

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Bluecon International B.V.

As to Bluecon International B.V., it is agreed between the Parties that, to the best of their knowledge no data, know-how or information of Bluecon International B.V. shall be needed by another Party for the Project or exploitation of the Foreground.

This represents the status at the time of signature of this Consortium Agreement.

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Boskalis Environmental B.V.

As to Boskalis Environmental B.V., it is agreed between the Parties that, to the best of their knowledge no data, know-how or information of Boskalis Environmental B.V. shall be needed by another Party for the Project or exploitation of the Foreground.

This represents the status at the time of signature of this Consortium Agreement.

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Chemours Netherlands B.V.

As to Chemours Netherlands B.V., it is agreed between the Parties that, to the best of their knowledge no data, know-how or information of Chemours Netherlands B.V. shall be needed by another Party for the Project or exploitation of the Foreground.

This represents the status at the time of signature of this Consortium Agreement.

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DiaCCon GmbH

As to DiaCCon GmbH, it is agreed between the Parties that, to the best of their knowledge no data, know-how or information of DiaCCon GmbH shall be needed by another Party for the Project or exploitation of the Foreground.

This represents the status at the time of signature of this Consortium Agreement.

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echemtech

As to echemtech, it is agreed between the Parties that, to the best of their knowledge no data, know-how or information of echemtech shall be needed by another Party for the Project or exploitation of the Foreground.

This represents the status at the time of signature of this Consortium Agreement.

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Forever Analytical Solutions B.V.

As to Forever Analytical Solutions B.V., it is agreed between the Parties that, to the best of their knowledge no data, know-how or information of Forever Analytical Solutions B.V. shall be needed by another Party for the Project or exploitation of the Foreground.

This represents the status at the time of signature of this Consortium Agreement.

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Het Waterlaboratorium

As to Het Waterlaboratorium, it is agreed between the Parties that, to the best of their knowledge no data, know-how or information of Het Waterlaboratorium shall be needed by another Party for the Project or exploitation of the Foreground.

This represents the status at the time of signature of this Consortium Agreement.

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N.V. PWN Waterleidingbedrijf Noord-Holland

As to N.V. PWN Waterleidingbedrijf Noord-Holland, it is agreed between the Parties that, to the best of their knowledge no data, know-how or information of N.V. PWN Waterleidingbedrijf Noord-Holland shall be needed by another Party for the Project or exploitation of the Foreground.

This represents the status at the time of signature of this Consortium Agreement.

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Provincie Zuid-Holland

As to Provincie Zuid-Holland, it is agreed between the Parties that, to the best of their knowledge no data, know-how or information of Provincie Zuid-Holland shall be needed by another Party for the Project or exploitation of the Foreground.

This represents the status at the time of signature of this Consortium Agreement.

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Smurfit Westrock Roermond Paper B.V.

As to Smurfit Westrock Roermond Paper B.V., it is agreed between the Parties that, to the best of their knowledge the following Background is identified and agreed upon for the Project. Specific limitations and/or conditions, shall be as mentioned hereunder:

Describe Background	Specific limitations and/or conditions for the Project	Specific limitations and/or conditions for exploitation
Roermond Paper delivered analyses and or process information will only be used in the project.	Sharing any data from Roermond paper is only allowed after approval of Roermond Paper.	

This represents the status at the time of signature of this Consortium Agreement.

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Vereniging Innovatieve Geneesmiddelen

As to Vereniging Innovatieve Geneesmiddelen, it is agreed between the Parties that, to the best of their knowledge the following Background is identified and agreed upon for the Project. Specific limitations and/or conditions, shall be as mentioned hereunder:

Describe Background	Specific limitations and/or conditions for the Project	Specific limitations and/or conditions for exploitation
VIG members, pharmaceutical companies.	only until specific needs are expressed will our members be able to give consent.	only until specific needs are expressed will our members be able to give consent.

This represents the status at the time of signature of this Consortium Agreement.

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Vereniging van de Nederlandse Chemische Industrie

As to Vereniging van de Nederlandse Chemische Industrie, it is agreed between the Parties that, to the best of their knowledge no data, know-how or information of Vereniging van de Nederlandse Chemische Industrie shall be needed by another Party for the Project or exploitation of the Foreground.

This represents the status at the time of signature of this Consortium Agreement.

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Stichting Wageningen Research
Research institute Wageningen Food & Biobased Research

As to Stichting Wageningen Research, Research institute Wageningen Food & Biobased Research, it is agreed between the Parties that, to the best of their knowledge no data, know-how or information of Stichting Wageningen Research shall be needed by another Party for the Project or exploitation of the Foreground.

This represents the status at the time of signature of this Consortium Agreement.

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Stichting Wageningen Research
Research institute Wageningen Food Safety Research

As to Stichting Wageningen Research, Research institute Wageningen Food Safety Research, it is agreed between the Parties that, to the best of their knowledge no data, know-how or information of Stichting Wageningen Research shall be needed by another Party for the Project or exploitation of the Foreground.

This represents the status at the time of signature of this Consortium Agreement.

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Annex 3 - Template MTA

Material Transfer Agreement

THE UNDERSIGNED:

1 **[Party supplying the material]**, having its registered office at [address], [country], hereinafter also to as: "[Provider]";

and

2 **[Party receiving the material]**, having its registered office at [address], [country], hereinafter also referred to as: "[Receiver]";

Provider and Receiver are hereinafter individually also referred to as a "**Party**" and collectively as the "**Parties**";

Any capitalized term used in this material transfer agreement (hereinafter referred to as: "**MTA**"), but not defined herein, shall have the meaning ascribed thereto in the Consortium Agreement (see definition below).

WHEREAS:

a) Provider and Receiver are both a Party to the TKI research project called "Monitoring, removal and breakdown of PFAS in (waste) water." (hereinafter also referred to as: "**Project**") and have, together with some other parties (hereinafter also referred to as: "**Project Partners**"), entered into a Consortium Agreement on 1 June 2025 (hereinafter also referred to as the "**Consortium Agreement**");

b) Provider is the owner and/or holder of certain material, which is specified in Annex 1;

c) Receiver is interested in investigating this material for research purposes only for the Project to which the material shall be included as Background of Provider and Receiver is willing to provide the results of its research to Provider and the other parties to the Project;

d) Provider is prepared to make available to Receiver such material subject to the provisions of this MTA.

HAVE AGREED AS FOLLOWS:

Article 1: Supply and use of the Material

1.1 As soon as possible after this MTA has been signed by the Parties, and under the terms and conditions of this MTA, Provider or any of its Affiliates shall provide Receiver with certain material: [brief description of the material], as further specified in Annex 1 to this MTA (hereinafter referred to as the "Material"). Material means the above mentioned (biological) material including any (un)modified derivatives, progeny and any accompanying information and/or data in respect thereof.

1.2 Provider hereby grants Receiver a non-exclusive right to use the Material solely for performing its tasks within the Project (hereinafter referred to as: "**Activities**"). The Material shall be included as Background of Provider in the Project.

1.3 Unless expressly agreed otherwise, Receiver shall keep the Material towards third parties, other than the Project Partners, in strictest confidence in compliance with Article 5 of the Consortium Agreement and shall not provide (any part of) the Material to any third party, or otherwise disclose, release, license, lend, part with, or allow access to (any part of) the Material, without the prior written consent of Provider.

1.4 Receiver is nevertheless entitled to give its Affiliates’, and service providers access to the Material, as far as such involvement is permitted under the Consortium Agreement and necessary to perform the Activities. Receiver will ensure that its Affiliates, and service providers will hold the Material in strictest confidence and will use the Material strictly in accordance with the provisions of this MTA.

Article 2: The Material

2.1 The rights to the Materialbelong to Provider in as far as such (part of the) Material is not considered a result under Article 3.1.

2.2 Receiver undertakes not to disclose to any third party and/or publish that the Material originated from and/or has been supplied by Provider, unless Provider has given its prior written approval thereto.

2.3 Receiver shall use the Material in compliance with all laws and governmental regulations and guidelines applicable to the Material, including, where applicable, the conditions of the country where the Material originates (Mutually Agreed Terms (MAT) and/or Prior Informed Consent (PIC)), and shall ensure that it complies with such further arrangements as referred in Article 10.3 of the Consortium Agreement.

2.4 Receiver shall not make or have made any analysis of any Material received by it under this MTA for the sole purpose of determining its (chemical) composition, except to the extent necessary for the Activities.

Article 3: (Rights on) Results

3.1 Receiver shall provide the results of the Activities to the Project Partners. These results shall become Foreground in the Consortium Agreement.

3.2 Receiver is allowed to use these results with regard to the Material within its own organization and may share the results with its Affiliates, provided that that is permitted under the Consortium Agreement.

Article 4: Warranties and liability

4.1 Receiver agrees and acknowledges that the Material has been provided to Receiver without any warranty, either expressed or implied, with regard to its quality, stability, fitness for a particular purpose, or any other quality.

4.2 Provider makes no representations and extends no warranties, either expressed or implied, that the use of the Material in accordance with this MTA will not infringe any (intellectual property) right of a third party. Provider is however not aware of such conflicting third party's rights.

4.3 Receiver will not hold Provider and/or its Affiliates liable, neither jointly nor separately, for any damages suffered by Receiver arising from Receiver's use of the Material.

4.4 No right or licence, neither expressed nor implied, is granted to Receiver with regard to the Material or other IP Rights belonging to Provider and/or its Affiliates, except as explicitly set forth in this MTA.

4.5 Provider will process, pack and ship the Material in accordance with all applicable legislation and good industry practice.

4.6 Provider shall not be liable to Receiver for any damage or loss of Receiver due to or arising from the shipping and delivery and/or use, storage or disposal of the Material by Receiver. Receiver shall indemnify and hold Provider harmless against any claims that may arise out of Receiver's use, storage or disposal of the Material.

Article 5: Term and termination

5.1 This MTA shall enter into force on the date this MTA has been signed by the Parties, and shall remain in full force and effect until 31 May 2028.

5.2 After expiration of this MTA, the Articles 1.3 (Confidentiality), 2 (The Material), 3 ((Rights on) Results), 4 (Warranties and liability) and this Article 5 (Term and termination) as well as the Articles which, considering their nature, are intended to remain in force between the Parties after termination of this MTA, shall survive termination of this MTA.

5.3 After expiration of this MTA and upon request of Provider, Receiver shall immediately destroy or return all remaining Material and any derivatives thereof in its possession, such to the sole discretion of Provider.

Article 6: Applicable law and dispute resolution

6.1 This MTA and the performance thereof is exclusively governed by Dutch law.

6.2 The Parties shall attempt in to resolve any dispute arising out of or relating to this MTA amicably.

6.3 Should Parties fail to resolve a dispute amicably, then such dispute shall exclusively be judged by the competent court in The Hague, the Netherlands.

Agreed and signed by:

Provider	**Receiver**
______________________________	______________________________
By:	By:
Position:	Position:
Place:	Place:
Date:	Date:

Annex 1 to the MTA – specification of the Material

Unique identifier of supplying Party	Provider* (donor or collector)	Unique identifier of Provider*	Country of origin	Date the sample left the country of origin	Terms and conditions of Provider*

* Information to be supplied in case Material was obtained from a third party

Annex 4 - Invention Disclosure Form (IDF)

Title of the invention:

Date:

Submitted by (name and affiliation):

Part A. Description of the invention

Background of the invention (state of the art); why is the invention required, what problem is solved? Has it been tried to solve this problem before or by different means?

- Describe the background of the invention (3-4 paragraphs):
- Describe the problem(s) solved by the invention:
- Describe the differences from the state of the art:
- Has any patent search been carried out? If so, provide results.

Give a short description of the invention and the inventive steps (i.e. non-obvious steps which are crucial in obtaining the benefits of the invention).

- Description of the invention (3-4 paragraphs):
- Indicate the inventive steps:
- Describe the benefits of the invention:

Description of the research that resulted in the invention. Is it a result of a main project of the group? Is further research going to be conducted in the next twelve months? Will this research further contribute to the invention?

- Description of how invention has originated:
- In case of result from research project/theme give here the description of project/theme:
- Does the research continue in next 12 months?:
- Does the further research contribute to invention? How?:

Describe the development stage (how much further development is required for commercialization). Is funding needed?

- Describe the development stage (concept, proof of concept, prototype, etc.):
- Is further research or development required?
- Is funding needed?

When was the invention made? When was the first written record of the invention made? When was the first experimental demonstration of the invention (proof of concept) or how much time is needed to deliver proof of concept?

- Invention made (date):
- First written record of invention (date):
- Time needed for proof of concept (months):

Part B: Inventor details

Name only those who made an Intellectual Contribution (meaning actively conceiving the idea, in an important way contributing to the development of the invention and providing solutions to problems in and during the project). Mere efforts, ordinary assistance and the sharing of ideas, hypotheses and information, passively following instructions, performing routine tasks and executing result testing in and during the project do not constitute to an intellectual contribution to the inventive step of the invention. Please note that inventorship is not the same as authorship and has important legal implication in the procedure for acquiring patent protection. An inventor is somebody who made an Intellectual Contribution to the invention.

Inventor 1:

- Full Name:
- Function Title:
- Employer:
- Details of third party payment covering employment:

Inventor 2:

- Full Name:
- Function Title:
- Employer:
- Details of third party payment covering employment:

Inventor 3:

- Full Name:
- Function Title:
- Employer:
- Details of third party payment covering employment:

Inventor 4:

- Full Name:
- Function Title:
- Employer:
- Details of third party payment covering employment:

If more inventors are involved, please add all names.

In case of more than 4 inventors, please add all names and details and also in the right order of first inventor, second, etc***.***

Part C: Intellectual Property information

Give full details of funding sources of the research that led to the invention. Research contract details, terms of the contract covering Intellectual Property (provide copies if applicable). This information is needed to establish third party rights.

- Give details of funding sources of the research:
- Give research contract details:
- Give terms of the contract concerning IP (provide copy):

Give full details of the materials used in the research (including for instance special software programmes) and any Material Transfer Agreements (MTA) that are applicable.

- Details used materials:
- Details used software programmes:
- Details of MTA (provide copies where applicable):

Part D: Disclosure

Please list any previous or anticipated disclosures of information that could be relevant for the invention. This includes publications, abstracts, posters, lectures in public meetings as well as disclosures to colleagues from other organisations. These may affect the patentability and the time of filing. Please, provide information of all relevant publications in the field of invention, including background publications, conference abstracts, relevant patents or patent applications, etc.

- Previous or planned disclosures of information:
- Relevant publications:
- Disclosures to others:
- Patents:
- Key words for searching databases and markets

Part E: Commercial information

Provide any details that may help to assess the commercial potential of the invention. In particular list any companies that you know use or exploit the type of technology and detail any interest they may have (shown) in your research.

- Describe commercial perspectives for the invention:
- For what market segment is the invention relevant (e.g. agro-chemical; food; medical; pharma; plant breeding; veterinary; etc.)
- Give names of companies that could be interested:
- Give names of any research group working in the same area:

List any thoughts you have as to how the invention could be exploited. I.e. will it lead to new research projects that could be funded externally, can the technology/product be sold in the next years, is the invention suitable for a spin-off company?

- Perspectives for commercialisation:
- Interest in new research to be funded externally:
- Interest in selling the invention:
- Interest in using the invention for spin-off:

Annex 5 - IP Flow Scheme

Step 1: In case of Foreground which potentially can be protected by an IP Right, the researchers of the Parties involved describe the invention in an IDF including percentage (%) inventorship. The draft IDF is sent to all Parties for their review.

Step 2: The Project Committee has to verify the inventors indicated in the IDF and their percentage inventorship, before the IDF is made final and is signed.

Step 3: The owners shall send the final IDF to all Parties with the request to inform the Project Committee of their interest in exploitation of the potential IP Right(s) within their Field of Use.

Step 4: The Project Committee verifies whether the arrangements on ownership of IP Rights between all interested Parties are made in accordance with the "Guidelines for determining ownership IPR" as described below.

Step 5: If Partner(s) want to become full owner of IP Right(s) in accordance with step 4, and the Knowledge Institute is a co-owner, then such Partner(s) and Knowledge Institute determine the Market Conditions of such IP Right(s) in accordance with Article 9.8 of the Consortium Agreement. If applicable, the acquiring Partner(s) who shall become the owner(s) of IP Right(s) shall remunerate the Knowledge Institute for the transfer of the IP Right(s), thereby taking into account the in-kind, cash, Background contribution and percentage (%) inventorship of Parties. These conditions are arranged in a transfer agreement. If Partner(s) transfer(s) the ownership to the Knowledge Institute, then no remuneration of the Knowledge Institute to the Partner(s) is due.

Step 6: Owner(s) of IP Right apply/applies for or register(s) the IP Right in its/their own name, and assume(s) all costs of filing and maintenance. In case no agreement on step 5 is reached within 6 months or within 2 months when filing is urgent (as mentioned in Article 9.3 of the Consortium Agreement), then the Knowledge Institute will apply for or register the IP Right(s) in order to secure the priority date and costs of such filing will be equally split between the owners, unless agreed upon otherwise. All owners of this Foreground will be named as applicants of the IP Right. In such case, the Knowledge Institute and the concerned Parties shall agree on the ownership and exploitation of such IP Right in accordance with the Consortium Agreement.

Step 7: Licence arrangement(s) between each interested Party and the owner(s) of IP Right(s) will be negotiated in good faith and will include among others the following: Field of Use, territories, royalty payments (offset by own contributions, and taking into account market value), payments for maintenance of IP Right(s), extension of IP Right(s) to specific countries, and any other costs that might be connected to the IP Right(s) (i.e. oppositions, infringement, termination, litigation). When a Partner is interested in a license and has transferred its ownership to the Knowledge Institute (step 6), this transfer of ownership will be compensated as part of the licencing agreement to this Partner.

Step 8: Exploitation of IP Right(s) by owner and each interested Party by means of a license.

Guidelines for determining ownership IP Right(s)

When a Knowledge Institute is co-owner of the Foreground, co-ownership of IP Rights with the Knowledge Institute is not possible. And therefore the following applies:

Option 1:

- The application area of the IP Right(s) is within the Field of Use of the co-inventing Partner(s) and there is no interest from other Partners:

    - Knowledge Institute(s) transfer(s) ownership of the IP Right(s) to Partner(s) in accordance with Article 9.

Or
Option 2:

- The application area of the IP Right(s) is larger than the Field of Use of the co-inventing Partner(s) and there is no interest from other Partners:

    - Unless Project Committee decides otherwise, Partner(s) transfer(s) ownership of the IP Right(s) to Knowledge Institute in exchange for a licence in accordance with Article 9.

Or
Option 3:

- Multiple Partners have expressed their interest in the IP Rights and their Fields of Use overlap:

    - Unless Project Committee decides otherwise, Partner(s) transfer(s) ownership of the IP Right(s) to Knowledge Institute in exchange for a licence in accordance with Article 9.

Annex 6 - List of Affiliates

No applicable affiliates to this project.

Annex 7 - Accession document

ACCESSION

of a new Party to Consortium Agreement, version […, YYYY-MM-DD]

[OFFICIAL NAME OF THE NEW PARTY]

hereby consents to become a Party to the Consortium Agreement identified above and accepts all the rights and obligations of a Party starting [date].

[OFFICIAL NAME OF THE COORDINATOR]

hereby certifies that the consortium has accepted in the meeting held on [date] the accession of [the name of the new Party] to the consortium starting [date].

This Accession document has been signed by:

[Date and Place]

[INSERT NAME OF THE NEW PARTY]

Signature(s)

Name(s)

Title(s)

[Date and Place]

[INSERT NAME OF THE NEW COORDINATOR]

Signature(s)

Name(s)

Title(s)